Application of drone photogrammetry in hazard assessment in Međine municipality

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Abstract: After heavy rainfall at the beginning of September 2023 in the municipality of Međine, 6 km southwest of Mostar, debris flow appeared, which caused minor material damage to the surrounding buildings. Immediately after the appearance of the **debris flow**, a wider area of 160 ha was recorded using a drone to analyze the hazard, which, over time, contributed to the formation of the alluvial fan on which the site is located. The recording was done with the DJI Mini 2 drone, and the resulting photos were further processed with different software. Agisoft Metashape generated a point cloud, a 3D terrain model, an orthophoto, and a digital terrain elevation model (DEM) based on 337 photographs. The DEM image was used in further analysis within the FlowR software to obtain a debris flow simulation. An orthophoto was used to validate the simulation.

Keywords drone, model, debris blow

Introduction

Geological hazards represent one of the main threats to urban and rural populated areas, especially in hilly and mountainous regions. Many settlements are built in areas that are subject to geological hazards. The settlement of Međine, with about 200 inhabitants, was built on an alluvial fan. Debris flows, and floods periodically occur on alluvial fans, which puts the population and material goods at risk during periods of heavy rainfall. Human activity and changes in climatic conditions can lead to increased risk, where extreme temperatures and periods without precipitation, followed by extreme rainfall, are increasingly common. In November 2023, a debris flow formed after heavy rain, which caused material damage to the buildings.

After the occurrence of the debris flow, the terrain was photographed with an unmanned aerial vehicle to obtain photos to generate a 3D terrain model, a Digital Elevation Model (DEM), and an Orthomosaic, which were used for hazard analysis in the Flow-R program.

Geological structure

According to the geotectonic rezoning of Bosnia and Herzegovina, three large structural-facies units were distinguished: the Inner Dinarides, the Transition Zone, and the Outer Dinarides (M. Mojičević, J. Papeš, S. Čičić, 1984.)

The area of interest for this pepper is part of the structural-facies macro unit of the Outer Dinarides, which was formed on the Mesozoic carbonate platform. Geotechnically, it expresses the greater part of Herzegovina, southwestern Bosnia, and part of western Bosnia. In the belt of the Outer Dinarides, compressional fold structures, anticlines, synclines, extensive thrusts, and reverse and horizontal shear faults prevail. Numerous pull-apart basins, positive and negative "flower" structures, are genetically linked to fault zones. The lithological composition of the Dinarides is dominated by a thick series of micro tectonically cracked Mesozoic limestones, limestones with dolomite inlays, and dolomite.

The area of interest belongs to the geological map sheet Mostar K33-24, which covers an area of 1498 km² between coordinates 17°30' to 18°00' east longitude and 43°20' to 43°40' north latitude according to Greenwich. The most significant part of the terrain belongs to the high mountains of Herzegovina: Čvrsnica, Prenj, Čabulja, Velež, and Plasa, which have a Dinaric direction and are characterized by a complete absence of vegetation. Towards the south, the high Herzegovinian mountains pass into the surface with an average height of about 1000 m. A particular morphological unit is represented by karst fields, Bijelo polje, Rudno polje, Blidinje jezero, smaller karts fields around Lištica, and Mostarsko blato in the southern part of the field, where the site of interest is located. Mostarsko blato is located west of Mostar and represents a typical periodically flooded karst field.

According to the geological composition of the wider area, Cretaceous sediments are the most dominant, represented by massive and layered limestones and dolomites, which lie concordantly over the Jurassic sediments. The Lower and Upper Cretaceous have been established, but in the research area relevant to this work, the Cretaceous sediments of the Cenomanian and Turonian are present.

Limestones and dolomites of the Cenomanian lie concordantly over the Lower Cretaceous; larger parts were isolated in the area of mountain Čabulja, Velež, and Jasenjana, and smaller parts were found around Crnač and Lištica. In Lištica, which flows through the Mostarsko blato, dolomites dominate compared to limestone. The thickness of separated sediments is around 250m.

Sediments of the Turonian age lie concordantly over Cenomanian limestones and dolomites. They are represented on the mountains of Čabulja, Velež, Jasenjin, Varda, and Bogdola, and smaller parties were observed north and northeast of the list. Dolomites are finely crystalline, and smaller amounts of microcrystalline calcite are present in addition to dolomite crystals. The thickness of the mentioned sediments is around 400m.

Alluvial sediments are found in the Lištica valley, represented by fine and coarse gravel, less often by sand, which occurs in uneven stratification with frequent sandy clays. Also present are proluvial deposits, which represent formations built from clastic material created by the action of occasional linear flows, and torrents, where the erosion is intense and short-lived. This process often causes accompanying phenomena, such as landslides and landslides. The conditions for creating proluvial deposits are heavy rainfall, pronounced relief, and abundant yield of eroded material. Deposits are often deposited in fans at the foot of mountain echoes, at the outlet of smaller streams on the alluvial plains of larger rivers, and the like. These morphological forms are frequent in arid and semiarid areas, where there is rare but very abundant and heavy rainfall. Typical fans vary in length from decameters to kilometers, and their thickness ranges from meters to decameters.

The fan's general characteristic is the material's non-roundness and weak attachment to the gradation sorting from the root to the periphery of the cone. The gradational deposition of material occurs due to the decrease in the kinematic energy of the flow so that at the root of the fan, there are primarily pieces of rock, coarse-grained pebbles. At the same time, finer-grained deposits, such as gravel and sand, are found in the lower parts, and the smallest sediments are present on the peripheral parts of the fan.

Geomorphological features

According to A. Leprica (2018), the Mostarsko blato represents a neo-tectonically lowered valley, dominantly characterized by accumulation processes. Geomorphologically, it was reshaped within fault-predisposed pull-apart basins. Based on the results of geological analyses, it was established that the slopes of larger fields in the karst and some valley extensions in the Outer Dinarides were filled with Neogene lakes that communicated with each other. Today, the Mostarsko blato is a periodically flooded field where lacustrine and bar sediments are deposited to cover the lowest parts of the field. And form today's peatland. The wider area is made of carbonate rocks, limestone, and dolomite, which are quite susceptible to physical and chemical surface decomposition.

Physical and chemical decomposition are closely related and act together, but the intensities are usually different. Limestones and dolomites, as monomineralic rocks, are not subject to thermal decomposition. Still, the crystallization of salt and freezing of water leads to the physical decomposition of rocks, creating and expanding cracks that enable more intense chemical decomposition. The main agents of chemical decomposition are water, oxygen, carbonic acid, and organic acids. Chemical alteration leads to a decrease in the mechanical strength of the rock so that the physical decay is facilitated and intensified, which again leads to an increase in the chemical decay and to the complete decay of the rock and its erosion. In the process of karst erosion, carbonic acid is the most important, created by dissolving carbon in water, thus increasing the solvent power of water by about 100 times. It should be taken into account that although dolomites are carbonate rocks, they are much less sensitive to chemical decomposition than limestone, about 20 times less.

Karst areas with many dilapidated and decomposed rocks are suitable for denudation, in which loose soil and decomposed rock are washed away underwater, leaving bare rocks (Figure 1). The intensity of denudation depends on the amount of precipitation, the terrain's slope, the soil's composition, and the vegetation cover.

Figure 1 - Aerial photograph of Međine

Slope processes develop on terrains covered by intense physical and chemical erosion. For this paper's case, the proluvial process and proluvial deposits are essential. Proluvial deposits represent clastic formations formed by torrential flows, and the conditions for their formation are heavy rainfall, pronounced relief, and an abundant yield of destroyed material.

Climate characteristics

The temperature of this area is characteristic of the northern hemisphere and the area of moderate latitudes. The average annual temperature has a regular development; the warmest month is August, and the coldest is December. In the summer months, it is not uncommon for temperatures to exceed 40°C; the coldest month is January, with an average temperature of 5°C, and the hottest month is July, with an average temperature of 26°C. Mostar has a relatively dry season from July to September, and the rest of the year is humid with a mild climate. The highest temperature in Mostar was measured on July 31, 1901. year and was 46.2°C.

Next to temperature, precipitation is the most critical climate element. Cyclonic precipitation prevails in Herzegovina, and Herzegovina belongs to the Mediterranean pluviometric regime characterized by distinct winter maximum and summer droughts.

The debris flow formed in November after daily rainfall of 31.3 mm, although it should be taken into account that although the measured interval was 24 hours, the rainfall lasted only a few hours. The Federal Hydrometeorological Institute of Bosnia and Herzegovina provided data on the amount of precipitation.

Formation of the debris flow

After heavy rainfall, debris, decay, and soil suddenly moved under the action of water. This is a proluvial process where the agent is the kinetic energy of occasional linear flows. The erosive effect of the flow that occurred in Međine was immediate. It caused the movement of rubble, the volume measured in m^3, and created a ravine.

Figure 2 - Ravine created by debris flow and deposited material

The material was transported along the ravine, 650m, then moved 250m through the settlement, and as the flow lost its kinetic energy, the material was sorted by size.

The factors that caused erosion are:

• precipitation, November 3, 2023. year were so and so, which contributed to the increase in the kinetic energy of the flow

• the absence of vegetation enabled easy washing of materials from the slopes, their transport, and disposal on the lower parts of the terrain.

In conversation with the locals, I learned that in the 1950s, a debris flow that was larger than the watershed in 2023 was formed. This caused significant material damage to the buildings. In recent years, part of the construction material from the damaged buildings has been found in the bottom of the fan, covered with a thin layer of humus.

Specific remedial measures can be taken to prevent the occurrence of such water bodies, which include reducing erosion, shortening the length of material transport, and building an anti-flood barrier.

Research methods

The methods used to process the investigation area are remote sensing methods, which, in the narrower sense, include analyzing and interpreting images of parts of the Earth's surface, whether taken from the ground, air, or space. One of the widely used remote sensing methods is digital photogrammetry.

Photogrammetry is an optical technique based on the stereo principle, that is, on the existence of parallax between two recording positions. Parallax represents an apparent change in the object's position relative to the background due to the difference in the observation position or due to the rapid movement of the observer. In the photogrammetric analysis, recordings of the visible part of the spectrum and a high-resolution camera are used, whereby the recordings are performed with an overlay to achieve a stereo effect.

By applying digital photogrammetry, 3D models of the object of interest, in this case, the terrain, can be obtained using digital images. Footage can be obtained in different ways, such as by using other platforms like helicopters, airplanes, or drones.

The geometry of the shot is reconstructed based on the recognition of the same object on two or more different shots (that's why it is necessary to perform a recording with an overlay), and based on the geometry of the camera lens, knowledge of the position from which the recording was made and the stereo effect, the x,y,z coordinates of the recognized object are obtained of the object. The procedure is repeated until sufficient points are reconstructed to form a 3D terrain surface.

The main goal of photogrammetry is to determine the geometrical dependence between the object and the photograph and collect information about the object from the picture. Digital photogrammetry involves processing all types of images, passive (obtained by an optical system) or active (obtained by an active system), taken from any platform, be it a pocket camera, drone, airplane, or satellite.

Aerial photography was used to write this paper. Aerial photography can be done vertically or obliquely. In vertical images, the optical axis is perpendicular to the horizontal plane. In oblique shooting, the camera's optical axis coincides with the horizontal plane at an angle smaller than 90 degrees. Decreasing this angle increases the area of the recorded terrain and the deformations that appear on the video due to the perspective, which is not uniform. Parts of the terrain closer to the camera are much less deformed than areas further away. In vertical images, deformations also occur, which are evenly distributed and grow from the center of the image to its periphery. Although oblique shots cause deformations when recording, the same part of the terrain must be recorded twice from two different positions. There must be a certain convergence angle between the axes, meaning that at least one axis must have an oblique position about the horizontal plane. The requirements are contradictory, but a solution is easily reached by recording the terrain with overlapping shots so that the part where the shots are overlapped is recorded twice from two different positions. The required overlay during recording should be a minimum of two-thirds of the image because an overlap of 50% of the image surface does not provide sufficient certainty that each point of the terrain will be captured twice from two different positions.

Research results

The research area covers an area of 160ha and was recorded with a DJI Mini 2 drone for photogrammetric analysis of the area, dated November 4, 2023. immediately after the start of the flow, the recording was made. Three hundred twenty-seven photos with mutual overlap >60% were taken.
In the Agisoft Metashape program, a 65 million-point cloud was generated based on previously taken photos. The point cloud was later used to generate the 3D terrain model shown in Figure 3.

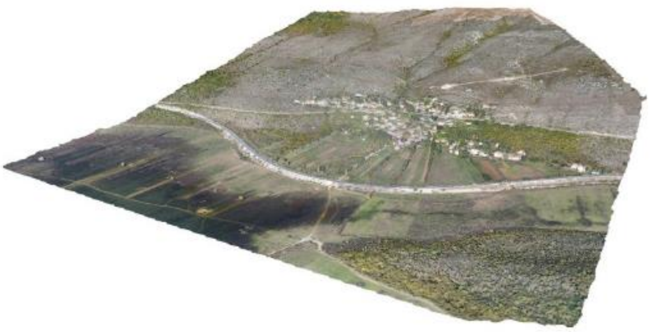

Figure 3 – 3D model of research terrain

Subsequently, the point cloud was filtered in Agisoft Metashape and CloudCompare. With the help of the CloudCompare program, vegetation removal from point clouds was also performed, in addition to filtration. The Agisoft Metashape program also generated an orthophoto of the area, which includes the area above the site, the site itself, and part of the karst field. The resolution of the orthophoto image is 12 cm and clearly shows the area affected by the debrie flow, Figure 4. In addition to the orthophoto, a digital terrain elevation model (DEM) with a resolution of 24 cm was also generated, Figure 5.

Figure 4 – Ortofoto of research terrain

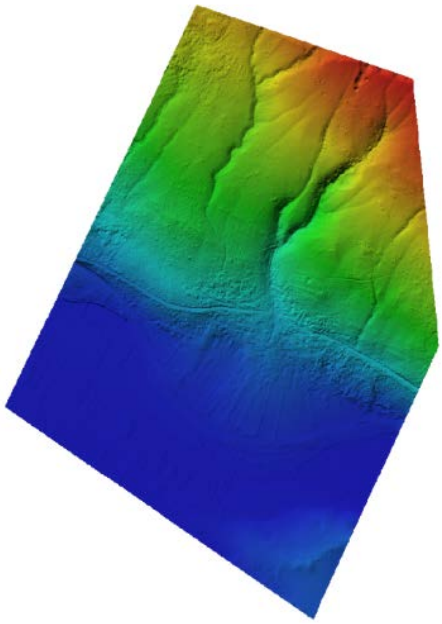

Figure 5 – Digital Elevation Model of research terrain

Using the Flow-R program, the debris flow simulation was made. The modified Holmgren algorithm (1994) was used as the direction algorithm, and the Perla et al. (1980) function was used as the friction loss function. Iterations were performed with different parameters until the result corresponded to the actual situation in the field. If the simulation result is compared with the orthophoto image, it can be concluded that the simulation is valid. Also, by changing the parameters, the very creation of the fan on which Međine is located can be shown.

Figure 6 – Result of Flow-R simulation

Conclusion

The rapid advancement of technology has led to drones for commercial service, providing outstanding footage that can be used for a variety of purposes for little money. On the recordings obtained by the DJI Mini 2 aircraft, which are subsequently processed in various software, a spatial analysis of the terrain can be done, accompanied by animations and photo documentation, which is of satisfactory quality even for professional use. With a high-quality analysis and interpretation of the results, suggestions can be made for protection against natural disasters and improvement of urbanization. Still, it is also essential for the user to recognize insufficient initial data and interpret them well.

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