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ASPECTS REGARDING THE ESTIMATION OF THE FLOOD LIMITS USING AN UAV IN ORDER TO HYDRAULIC DESIGN WATER MANAGEMENT WORKS

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Abstract

The present paper aims to highlight a more efficient and safer way to estimate the flood limits especially in hard-to-reach areas (hill-mountain) in order to reduce the calamities caused by flash-floods through water management works. It was used an UAV (drone) with D-RTK technology together with a GPS station with which there were captured elevation points on the ground. The study area is located in Alba County on the Răchita Valley near the Sebeș city, area having a strong torrential character, especially during short-term and high-intensity rains. In 2019-2020 winter, a flood of 106 m^3/s was recorded, representing a huge value compared to the multiannual flow of the main water course of 8.88 m^3/s. The estimation of the flood limits is fully computerized, obtaining the most accurate results in order to be able to design hydraulic specifications for hydrotechnical schemes and structures needed considering both structural and environmental sides.

***Key words**: D-RTK, flash-flood, flood limit, hydraulic works, UAV.*

INTRODUCTION

As known, or rather, as felt, the climate changes, are present, the most efficient way to response is immediate adaptation. Over the past 20 years, Romania has experienced increasingly extreme phenomena such as extreme drought or rapid floods. Unfortunately, engineering works for flood defense or irrigation to combat those phenomena are outdated in the current context. Through this paper, it is highlighted the fact that technological expansion is as useful as it can be.
Located in the South-Eastern Europe, on the lower course of Danube and at the Black Sea seaside, the Romania territory (237,502 km^2) presents a unique diversity of natural conditions and resources, long processes and climatic changes generated during various geological periods, a large complexity of relief forms appeared on the Romanian territory, characterized however by proportionality and harmony (Marinescu, 2000).
Following the new trend of 21st century technology and at the same time seeing how efficient a UAV has become in the processes of sizing/designing/executing engineering works, it is important to present a series of aspects related to how the flood limit can be graphically represented.
Data acquisition using the principles of aerial photogrammetry is a modern method that allows surveying a large amount of data in a short time compared to classical topography methods. The data can be retrieved using opto-electronic or optical-mechanical sensors that are located on board aircraft. In this case, UAV (unmanned aircraft vehicle) technology was used, also called a drone, equipped with an RTK module that allows real-time corrections (Vorovencii, 2010; Carvajal, 2011; Raeva, 2016).

MATERIALS AND METHODS

The study area is located in Alba County on the Răchita Valley near the Sebeș city (Figure 1). The Răchita stream (cadastral code IV-1.102.14) is 5 km long with 10 km^2 hydrographic basin and an altitude of 550 m. In this sector, the stream has a slope of 1%, thus the floods propagate at high speed with an accentuated destructive effect. The climate of the Rachita valley belongs to the continental hill and plateau climate with altitudes of 300-600 m. The average annual air temperature varies between 8 and 21°C.

From geo-morphological and structural point of view, Răchita valley belongs to the Secase Plateau. The particularities of the relief in the area are closely related to the evolution over time of the great unit of the Transylvanian Basin, the South-South East Zone.

The field survey took place in August 2023, where we captured various scenarios with the help of the UAV.

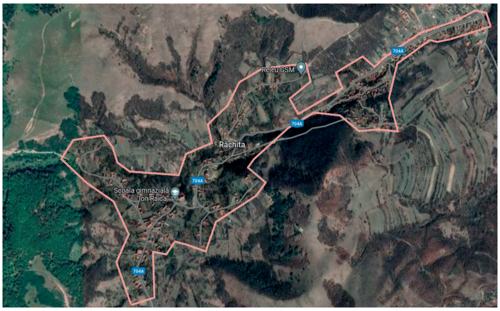


Figure 1. Aerial representation of area of study- source Google Earth

The equipment's used to carrying this work are DJI D-RTK 2 Mobile Station and the DJI Mavic 3 Enterprise. Stonex 980+ base station and Stonex 990+ we use as an over.

The DJI D-RTK 2 mobile station is a high quality and easy to use electronic station with high-precision GNSS receiver that supports all GPS, GLONASS, Beidou and GALILEO signals providing real-time accuracy. This equipment was used to collect ground points to have a good accuracy, optionally it could be used the GPS subscription offered by ROMPos, but in that area, there wasn't sufficient GPRS signal, which is why it was used the D-RTK station.

The DJI Mavic 3 Enterprise RTK UAV system has an RTK module and can receive signals from GNSS systems: GPS, Galileo, Glonass, and Beidou. With this module it is possible to position in real time with very high accuracy, requiring a small number of ground control points. In this case it was turned on the obstacle sensor because the drone reaches a speed of 90 km/h and 45 minutes flying operate with one battery.

The Stonex 980+ was used as a base station and Stonex 990+ as a rover, this equipment helped to compare the accuracy of the ground points that was collected with D-RTK Mobile Station.

Positioning using GNSS technology was used to determine the photogrammetric landmarks. The real-time kinematic method Real Time Kinematic (RTK) radio rover base was used, which allows the transmission of real-time corrections and ensures centimeter accuracy. (Dierwechter, 2008; Lwin, 2012)

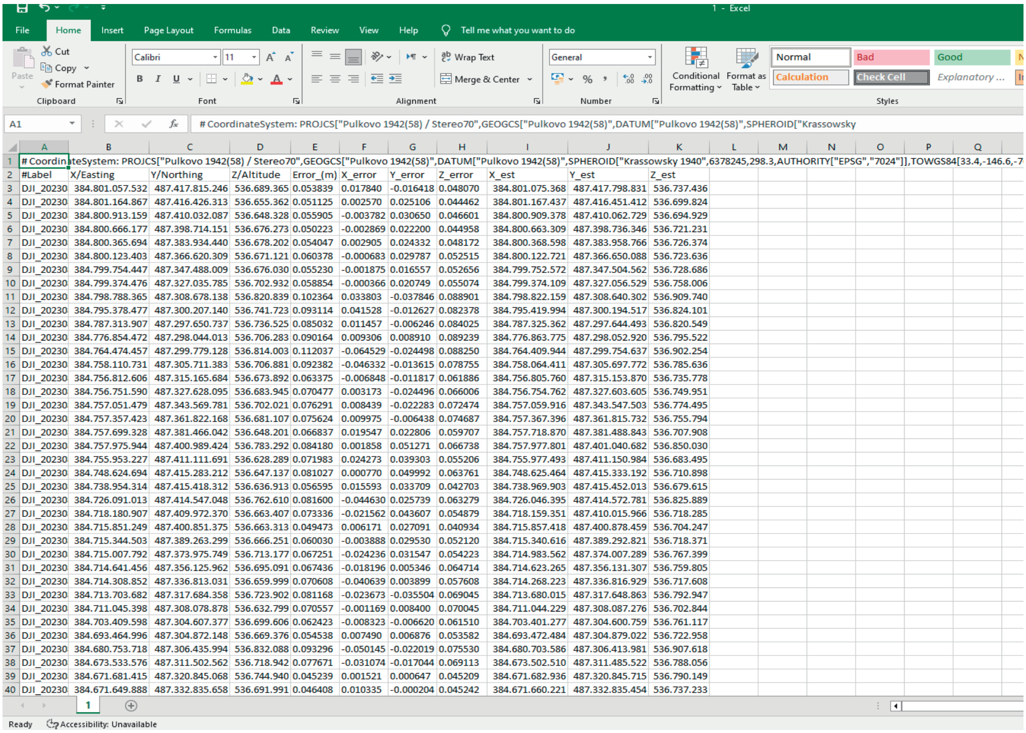
Software applications to obtain the data were:

- DJI Pilot 2 for flight mission;
- GStar Cad 2023 for marking plans;
- Pix4D Mapper we used to process images and orthophotoplan;
- GlobalMapper used for photogrammetric data processing;
- TransDatRO for transforming the coordinates taken with the UAV.

To initiate the aerial photography project, it is necessary to establish the direction of the UAV flight path, flight altitude, elevation plan, longitudinal and transversal coverage of the frame, total number of photographs taken, distance between the axes of photography, and the time required for the aerial photography mission. The UAV controller (DJI Rc Plus) comes pre-installed with the control application, namely DJI Pilot 2, which was used for flight planning and execution. A flight covering the entire valley was conducted. With the RTK module functioning on GPS frequencies: L1/L2, GLONASS: L1/L1, BeiDou: B1/B2, and Galileo: E1/E5a, the UAV ensures a positional accuracy of ±1.5 cm + 1ppm RMS vertically and ±1 cm + 1 ppm horizontally.

The mapping area was determined by the flight plan, which was automatically set based on manually input boundaries. The flight was set at a variable altitude of 100 m, following the natural terrain, with a frontal and lateral image overlap of over 80%, resulting in the collection of 738 images covering 37 ha of land. The integrated camera is housed within a gimbal with automatic image stabilization and mechanical shutter, leading to highly precise image stabilization. The sensor has a resolution of 20 megapixels and a 24 mm lens. Due to the use of the integrated RTK module along with the mobile D-RTK station, the number of ground control points was relatively low, and the error did not exceed 1 cm.

Throughout the mission, the UAV remained connected to the mobile D-RTK station, receiving corrections to improve its coordinates. The D-RTK station was connected to the UAV via the RC Plus remote controller, and, upon connection, significant improvements in elements such as latitude, longitude, and altitude were observed. The coordinates were taken from the WGS84 projection system (World Geodetic System 1984) and were trans-calculated in the TransDatRO application, then reintroduced into the software as in Stereo 70 (Figure 2). Following data processing, the Pix4D Mapper application generated a processing report containing details about the camera's location, residual errors, camera orientation errors, etc. The process of collecting the photos lasted 3 hours and 18 minutes.



CoordinateSystem: PROJCS["Pulkovo 1942(58) / Stereo70",GEOGCS["Pulkovo 1942(58)",DATUM["Pulkovo 1942(58)",SPHEROID["Krassowsky 1940",6378245,298.3,AUTHORITY["EPSG","7024"]],TOWGS84[33.4,-146.6,-7

#Label	X/Easting	Y/Northing	Z/Altitude	Error_(m)	X_error	Y_error	Z_error	X_est	Y_est	Z_est
DJI_20230	384.801.057.532	487.417.815.246	536.689.365	0.053839	0.017840	-0.016418	0.048070	384.801.075.368	487.417.798.831	536.737.436
DJI_20230	384.801.164.867	487.416.426.313	536.655.362	0.051125	0.002570	0.025106	0.044462	384.801.167.437	487.416.451.412	536.699.824
DJI_20230	384.800.913.159	487.410.032.087	536.648.328	0.055905	-0.003782	0.030650	0.046601	384.800.909.378	487.410.062.729	536.694.929
DJI_20230	384.800.666.177	487.398.714.151	536.676.273	0.050223	-0.002869	0.022200	0.044958	384.800.663.309	487.398.736.346	536.721.231
DJI_20230	384.800.365.694	487.383.934.440	536.678.202	0.054047	0.002905	0.024332	0.048172	384.800.368.598	487.383.958.766	536.726.374
DJI_20230	384.800.123.403	487.366.620.309	536.671.121	0.060378	-0.000683	0.029787	0.052515	384.800.122.721	487.366.650.088	536.723.636
DJI_20230	384.799.754.447	487.347.488.009	536.676.030	0.055230	-0.001875	0.016557	0.052656	384.799.752.572	487.347.504.562	536.728.686
DJI_20230	384.799.374.476	487.327.035.785	536.702.932	0.058854	-0.000366	0.020749	0.055074	384.799.374.109	487.327.056.529	536.758.006
DJI_20230	384.798.788.365	487.308.678.138	536.820.839	0.102364	0.033803	-0.037846	0.088901	384.798.822.159	487.308.640.302	536.909.740
DJI_20230	384.795.378.477	487.300.207.140	536.741.723	0.093114	0.041528	-0.012627	0.082378	384.795.419.994	487.300.194.517	536.824.101
DJI_20230	384.787.313.907	487.297.650.737	536.736.525	0.085032	0.011457	-0.006246	0.084025	384.787.325.362	487.297.644.493	536.820.549
DJI_20230	384.776.854.472	487.298.044.013	536.706.283	0.090164	0.009306	0.008910	0.089239	384.776.863.775	487.298.052.920	536.795.522
DJI_20230	384.764.474.457	487.299.779.128	536.814.003	0.112037	-0.064529	-0.024498	0.088250	384.764.409.944	487.299.754.637	536.902.254
DJI_20230	384.758.110.731	487.305.711.383	536.706.881	0.092382	-0.046332	-0.013615	0.078755	384.758.064.411	487.305.697.772	536.785.636
DJI_20230	384.756.812.606	487.315.165.684	536.673.892	0.063375	-0.006848	-0.011817	0.061886	384.756.805.760	487.315.153.870	536.735.778
DJI_20230	384.756.751.590	487.327.628.095	536.683.945	0.070477	0.003173	-0.024496	0.066006	384.756.754.762	487.327.603.605	536.749.951
DJI_20230	384.757.051.479	487.343.569.781	536.702.021	0.076291	0.008439	-0.022283	0.072474	384.757.059.916	487.343.547.503	536.774.495
DJI_20230	384.757.357.423	487.361.822.168	536.681.107	0.075624	0.009975	-0.006438	0.074687	384.757.367.396	487.361.815.732	536.755.794
DJI_20230	384.757.699.328	487.381.466.042	536.648.201	0.066837	0.019547	0.022806	0.059707	384.757.718.870	487.381.488.843	536.707.908
DJI_20230	384.757.975.944	487.400.989.424	536.783.292	0.084180	0.001858	0.051271	0.066738	384.757.977.801	487.401.040.682	536.850.030
DJI_20230	384.755.953.227	487.411.111.691	536.628.289	0.071983	0.024273	0.039303	0.055206	384.755.977.493	487.411.150.984	536.683.495
DJI_20230	384.748.624.694	487.415.283.212	536.647.137	0.081027	0.000770	0.049992	0.063761	384.748.625.464	487.415.333.192	536.710.898
DJI_20230	384.738.954.314	487.415.418.312	536.636.913	0.056595	0.015593	0.033709	0.042703	384.738.969.903	487.415.452.013	536.679.615
DJI_20230	384.726.091.013	487.414.547.048	536.762.610	0.081600	-0.044630	0.025739	0.063279	384.726.046.395	487.414.572.781	536.825.889
DJI_20230	384.718.180.907	487.409.972.370	536.663.407	0.073336	-0.021562	0.043607	0.054879	384.718.159.351	487.410.015.966	536.718.285
DJI_20230	384.715.851.249	487.400.851.375	536.663.313	0.049473	0.006171	0.027091	0.040934	384.715.857.418	487.400.878.459	536.704.247
DJI_20230	384.715.344.503	487.389.263.299	536.666.251	0.060030	-0.003888	0.029530	0.052120	384.715.340.616	487.389.292.821	536.718.371
DJI_20230	384.715.007.792	487.373.975.749	536.713.177	0.067251	-0.024236	0.031547	0.054223	384.714.983.562	487.374.007.289	536.767.399
DJI_20230	384.714.641.456	487.356.125.962	536.695.091	0.067436	-0.018196	0.005346	0.064714	384.714.623.265	487.356.131.307	536.759.805
DJI_20230	384.714.308.852	487.336.813.031	536.659.999	0.070608	-0.040639	0.003899	0.057608	384.714.268.223	487.336.816.929	536.717.608
DJI_20230	384.713.703.682	487.317.684.358	536.723.902	0.081168	-0.023673	-0.035504	0.069045	384.713.680.015	487.317.648.863	536.792.947
DJI_20230	384.711.045.398	487.308.078.878	536.632.799	0.070557	-0.001169	0.008400	0.070045	384.711.044.229	487.308.087.276	536.702.844
DJI_20230	384.703.409.598	487.304.607.377	536.699.606	0.062423	-0.008323	-0.006620	0.061510	384.703.401.277	487.304.600.759	536.761.117
DJI_20230	384.693.464.996	487.304.872.148	536.669.376	0.054538	0.007490	0.006876	0.053582	384.693.472.484	487.304.879.022	536.722.958
DJI_20230	384.680.753.718	487.306.435.994	536.832.088	0.093296	-0.050145	-0.022019	0.075530	384.680.703.586	487.306.413.981	536.907.618
DJI_20230	384.673.533.576	487.311.502.562	536.718.942	0.077671	-0.031074	-0.017044	0.069113	384.673.502.510	487.311.485.522	536.788.056
DJI_20230	384.671.681.415	487.320.845.068	536.744.940	0.045239	0.001521	0.000647	0.045209	384.671.682.936	487.320.845.715	536.790.149
DJI_20230	384.671.649.888	487.332.835.658	536.691.991	0.046408	0.010335	-0.000204	0.045242	384.671.660.221	487.332.835.454	536.737.233

Figure 2. Print Screen of Converting coordinates from WGS84 to Stereo 70

RESULTS AND DISCUSSIONS

For image processing, as mentioned earlier, it is used a specialized software package. For the basic stages, Pix4D Mapper was used, the post-processing steps being:

- *the first step* - alignment - it includes aerial triangulation (AT) and bundle block adjustment (BBA). At this stage Pix4D Mapper searches for feature points on the images and matches them across images into tie points.

The program also finds the position of the camera for each image and refines camera calibration parameters (estimates interior - IO and exterior - EO camera orientation parameters) (Figure 3).

- *the second step* - generation of a surface in 3D (mesh) and/or 2.5D (DEM). Polygonal model (mesh) can be textured for photorealistic digital representation of the object/scene and exported in numerous formats compatible with processing software, both for CAD and 3D modelling workflows.

The digital elevation model (DEM) is generated based on the point cloud data, and it can include either both terrain and all the objects above the ground, like trees, buildings and other man-made structures (digital surface model, DSM, only show the landscape of the territory, digital terrain model, DTM).

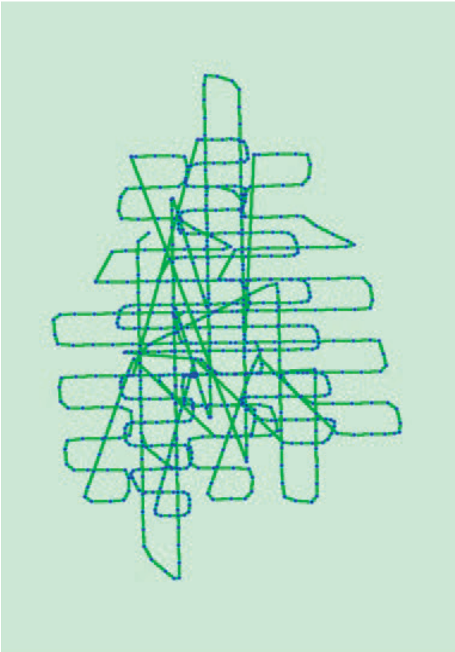


Figure 3. Top view of the initial image position. The green line follows the position of the images in time starting from the large blue dot

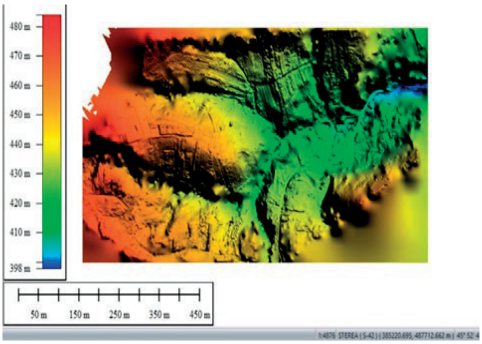


Figure 4. DEM Model

For the DEM model the error on the X coordinates is 0.020271 cm, for Y 0.022106 cm and for Z 0.045698 cm. For the X and Y coordinates, the error is represented by the root mean square of the ground control points and is 0.054662 cm, while the total error is given by the average of all ground control points and is 0.032691 cm. The elevations presented in Figures 3, 4, and 6 are represented by progressive colors, namely: blue represents the lowest elevation, while red represents elevations up to 120 m. Following the establishment of the flight path, the digital elevation model (DEM) has a resolution of 7.31 cm/pixel, and the point density is 35.7 points/m^2.

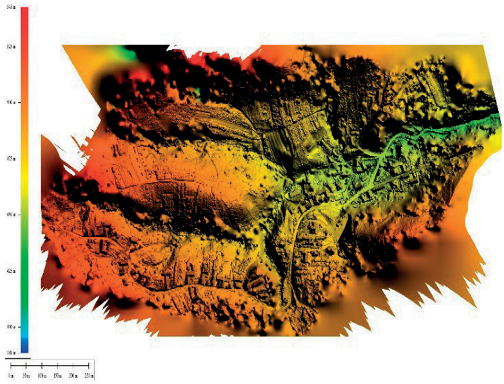


Figure 5. DTM Without Vegetation

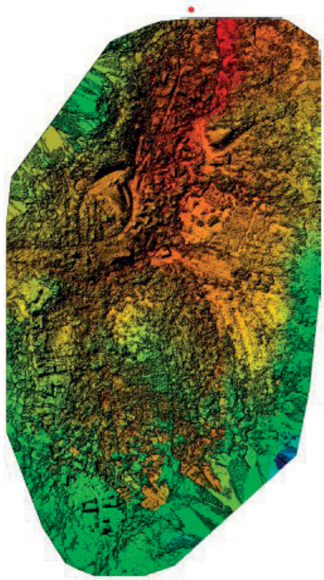


Figure 6. DSM Model with Vegetation

- *the third step* - creating of orthomosaic, which can be georeferenced and used as a base layer for various types of maps and further post processing analysis and vectorization. Orthomosaic is generated by projecting the images according to their EO/IO data on a surface of the user's choice: DEM or mesh (Figure 7).

Figure 7. Orthomosaic Model

The overlapping model shows the number of overlapping images computed for each pixel of the orthomosaic (Figure 8). Red and yellow areas indicate low overlap only 1 photo for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of key-points matches is also sufficient for these areas.

The UAV working altitude was 100 m with the terrain tracking function activated, and the ground sampling distance (GSD) being of 2.11 cm/pixel. The analyzed area covers 0.37 km^2, the number of aligned frames was 708. To identify the connection points, at least two images from the point cloud are required. In this case, there are a total of 2,357,685 connection points, along with an error of 0.185 cm/pixel, which represents the error between the distance to the projected point and the measured one. Based on the aforementioned steps, it can be developed the flood hazard boundary associated with the Rachita Valley. Subsequently, it is designed a reservoir in the pasture area of the village where it is possible to store the water volume from rapid floods.

Figure 8. Overlap Model

Based on the Digital Elevation Model and Digital Surface Model it was built the flood limit using GlobalMapper software. For the graphical representation of the limit, in concordance with the hydrological flows recorded and elaborated by the National Institute of Water Management (Tabel 1), where, based on the respective section of the studied basin surface, a maximum calculated flow of 52.4 m^3/s was obtained with various probabilities of exceedance, resulting in a water level elevation of 487 m.

As observed in the graphical processing, at the computational flow rate $Q_{1\%}$=52.4 m^3/s the water blade formed, flooding the Rachita village to the extent of 95% (Figure 9).

Table 1. Hydrological data (source: National Institute of Hydrology and Water Management)

Water Course	Section	F (km^2)	Hmed (m)	Q1% (m^3/s)	ρ %	γ	Grow time (h)	Total Time (h)
Rachita (IV.1.102.14)	x-386412.50 y-488058.88	4.50	487	52.4	27.1	0.24	4.5	18

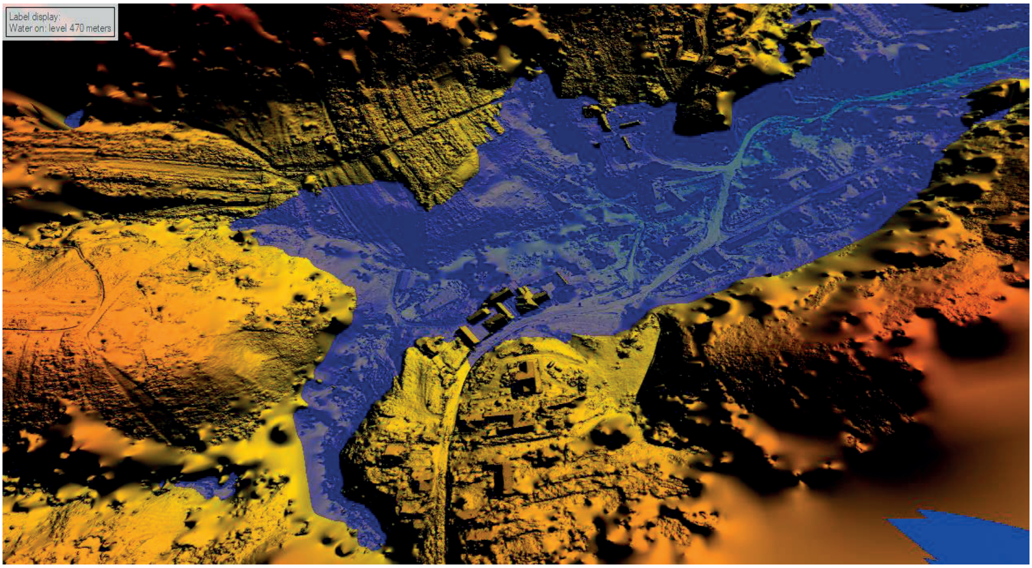


Figure 9. Flood Limit formed in Rachita Village

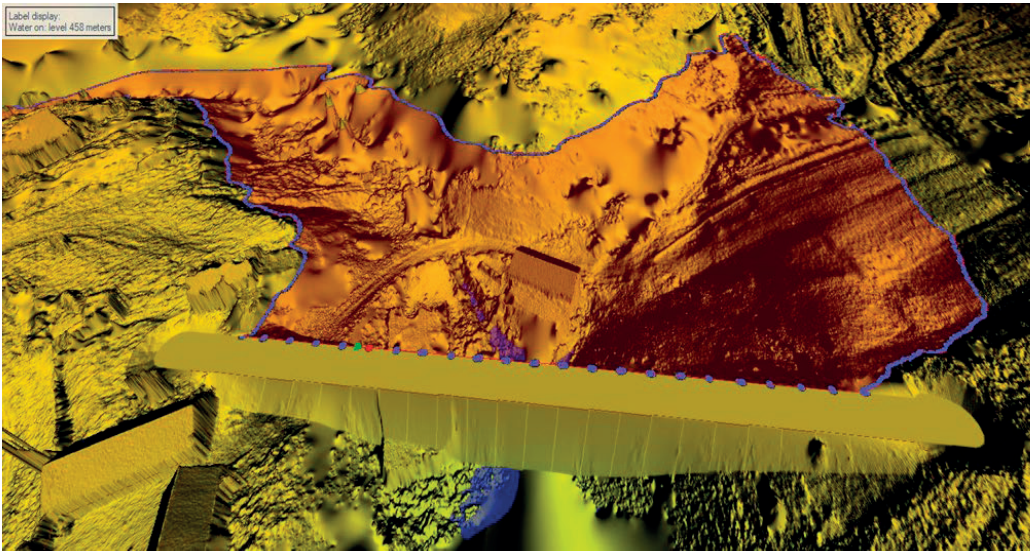


Figure 10. The Dam

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It can be observed what disaster a flash flood can cause when the flows from the slopes cannot be controlled. At a flash flood discharge of approximately 50 m^3/s, 90% of the commune is submerged, represents approximately 0.20 km^2. Analyzing the flood limit obtained it is obvious that the hole locality is under water, meaning it is necessary to find a technical solution to avoid this situation.

To prevent such disaster, it is appropriate to allocate a temporary space for the flood that does not endanger the adjacent population, and after the critical period has passed, it could safely transit the stored volume, working as a temporary reservoir.

On the previously obtained details and in accordance with the flow rates provided by the National Institute of Water Management, it is graphically designed a dam capable of withstanding the volume of water during the flood. The dam was designed upstream of the village of Răchita, where the village pasture is located. Based on the graphic processing and the input data, the dam has the following technical characteristics: the crest elevation reaches 438 m above sea level, while the riverbed elevation is at 412.50 m above sea level, resulting in a dam height of 26 m at the axis. The collected flow rates will be gradually released in line with the transit flow supported by the riverbed (Figure 10).

To properly dimension the temporary reservoir, the assistance of GlobalMapper software is needed, where using the Create Area function based on contour lines, the result is a storage volume of 55.291 m^3.

CONCLUSIONS

After analyzing the methods and results obtained through this study, it can be concluded that UAV equipment can significantly reduce the time needed to establish the flood limit, and furthermore, with the help of exported data, it is possible to design certain engineering works intended to protect the population against flooding.

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REFERENCES

Carvajal, F., Aguera, F., Perez, M. (2011). Surveying a Landslide in a Road Embankment Using Unmanned Aerial Vehicle Photogrammetry. (4) ISPRS, XXXVIII-1/C22: 201–206

Dierwechter, Y., Carlson, T. (2008). Effects of urban growth boundaries on residential development in Pierce County, Washington. *The Professional Geographer, 59*(1), 207-220.

Lwin, K.K., Murayama, Y., Mizutani, C. (2012). Quantitative versus Qualitative Geospatial Data in Spatial Modelling and Decision Making. *Journal of Geographic Information System, 1,* 235-241.

Marinescu, P., Lefter, L., Tecuci, I. (2000). Objectives of Romanian’s Resources Development (Chapter 1)- Romanian National Committee on Large Damns, Bucharest, Romania.

Raeva, P.L., Filipova, S.L., Filipov, D.G. (2016). Volume computation of a stockpile – a study case comparing GPS and UAV measurements in an open pit quarry. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXIII ISPRS Congress, Prague, Czech Republic, XLI-B1(4) 999–1004.

Vorovencii, I. (2010). *Photogrammetry*. Matrixrom Publishing House, Bucharest, Romania