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Preliminary Results in Assessing Flood-prone Areas Using UAS System within the Ozana River Upper Basin (the Eastern Carpathians)

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Abstract

The UAV technique, and more recently UAS systems, play an ever important role in various domains of research and practical activities. The increase in number of publications focusing on their applicability is spectacular. The objective of this study is to highlight the efficiency of an integrated command-overflight-taking photo system, in an area with obvious problems related to hydric hazards and risks. The quasi-circular shape, the petrography of the upper Ozana basin, its orientation and its opening to the air masses predominantly movement direction, represent just a few of the reasons why it was chosen as the case study. Also, the settlements are displayed on the valleys thread, and this confluence has a remuu potential, in case of isolated rains in the two related subbasins. The UAV Phantom 4 quadcopter, the UAS system, the DroneDeploy application, the UAVPhoto application, the Visual-SFM application, the Daisy algorithm, the micro triangulation network (mesh), the work surface textures, a hyper-resolution of orthophotoplan, DSM model with a 5 cm resolution etc. are the technical elements that made modelling at a very high detail possible. The probability flow rates that were used, were provided by the two hydrometric stations located very close to the study area. Theywere calculated using professional applications approved at the national gauging network level, using the established Krițki-Menkel and Pearson III statistical distributions. The cross-section profiles was performed in the 10.x ArcMap module, using the 3D Analyst extension, and the hydraulic calculation to obtain the average velocity was done using the Manning equation; subsequently, the floodable surfaces was delineated on these profiles. Using the same ESRI module, the flood prone area polygon interpolation and it overlapping over the terrain model and over the orthophotomap were achieved. Paradoxically, the analysis of the results indicates a low degree of the anthropogenic habitat damage, but this aspect is due, in large measure, to the intervention of technical teams in the recalibration of the minor riverbed, massively clogged by alluvial transport.

Keywords: *UAS, DSM, GIS, cross-section, flood prone area*

Rezumat. Rezultatele preliminare în determinarea arealelor inundabile folosind sistemul UAS în bazinul superior al Ozanei (Carpații Orientali)

Tehnica UAV, și mai recent sistemele UAS, își regăsesc tot mai mult locul în diverse domenii de cercetare și activități practice. Creșterea numărului publicațiilor privind aplicabilitatea acestora este spectaculoasă. Obiectivul prezentului studiu este de a pune în evidență eficiența unui sistem integrat de comandă-survol-fotografiere, pe un areal cu evidente probleme legate de hazarduri și riscuri hidrice. Forma cvasi-circulară, petrografia bazinului Ozanei superioare, orientarea și deschiderea acestuia pe direcția circulației predominante a maselor de aer, reprezintă doar câteva dintre motivele pentru care a fost ales ca studiu de caz. De asemenea, localitățile se înșiră pe firul văilor, iar confluența aleasă are un potențial de remuu, în cazul unor ploi izolate în cele două subbazine aferente. UAV Phantom 4 quadcopter, sistemul UAS, aplicația DroneDeploy, aplicația UAVPhoto, aplicația Visual-SFM, algoritmul Daisy, rețeaua de microtriangulație (mesh), texturile suprafeței de lucru, ortofotoplan hiperrezolut, model DSM cu rezoluție 5 cm etc sunt elementele tehnice care au făcut posibilă o modelare la un foarte mare detaliu. Debitele cu probabilități utilizate provin de la cele două stații hidrometrice situate foarte aproape de arealul de studiu și au fost calculate în aplicații profesionale omologate la nivelul rețelei hidrometrice naționale, folosind distribuțiile statistice consacrate Krițki-Menkel și Pearson III. Ridicarea profilelor transversale s-a realizat în modulul ArcMap 10.x, folosind extensia 3D Analyst, iar calculul hidraulic, pentru obținerea vitezei medii, a fost făcut utilizându-se ecuația Manning, ulterior suprafețele inundabile fiind delimitate pe profile. În același mod ESRI a fost realizată interpolarea poligonului de inundabilitate și suprapunerea sa peste modelul terenului și peste ortofotoplan. Analiza rezultatelor indică, paradoxal, un grad redus de afectare a habitatului antropic, însă acest aspect se datorează, în mare măsură, intervenției echipelor tehnice în recalibrarea albiei minore, colmatată masiv de transportul aluvionar.

Cuvinte-cheie: *UAS, DSM, GIS, profil transversal, bandă de inundabilitate*

Introduction

The debut of UAV (Unmanned Aerial Vehicle) technique and more recently UAS (Unmanned Aerial Systems) is related to the military applications and exercises, conducted in the United States of America and other countries with high financial and technical potential. Gradually, the UAV technique is being deployed in more strategic and other areas of the civil sector, from the supervision of natural and anthropogenic risk events, to the territorial management and supplies of products for commercial purposes, the latter being a new trend of the drone uses (Șerban et al., 2016, Ganová et al., 2017, Hackl et al., 2018, UAV Glossary of Terms, 2018).

Starting from the increasingly sophisticated mapping and monitoring needs, based in large part on a multi-scale analysis, it is standard procedure to combine the images collected using the UAV (UAS) technics with the satellite images, in order to achieve various photogrammetric, mapping, 3D modelling applications (Everaerts, 2008, Steffen and Foerstner, 2008, Sung Heuk et al., 2010, Eisenbeiss and Sauerbier, 2011, Remondino et al., 2011, Nadella et al., 2016).

On the other hand, numerous applications of the light flying techniques are implemented in forestry and agriculture, monitoring of vegetation (Sugiura et al., 2005, Hunt et al., 2010), as well as in the assessment of the health status of the forests, assuming the use of any performant electro-optical sensors, with taking pictures in the near-infrared domain (Watts et al., 2012).

In view of some risk generating natural factors manifestation, and the management of the generated crisis situations (Giordan et al., 2018), ever more frequently the UAV technique is used for landslides studying (Niethammer et al., 2010, Niethammer et al., 2011), soil erosion studying (D'Oleire-Oltmanns et al., 2012), but also for the detection of fires (Watts et al., 2009, Ambrosia et al., 2011) or monitoring the areas affected by earthquakes (post-earthquake) (Li et al., 2011, Baiocchi et al., 2013).

The micro-scale remote-sensing technique can be also successfully applied in the monitoring/surveillance of the road traffic, with travel time estimation, trajectories, the lanes occupancy degree (Puri et al., 2007, Remondino et al., 2011, Boccali et al., 2017), as well as in the air quality monitoring (Watts et al., 2012), in archaeology and cultural heritage (Chiabrando et al., 2011, Adjim et al., 2018) or in the resources mapping (Madjidab et al., 2018).

Within the hydric domain, the majority of the studies follow the problems related to the factors that triggered the floods or their effects in the territory. Here, the hydric risk is one of the major focus for researchers, along with structural or non-structural measures, which must be taken in order to mitigate this risk (Vârcol, 1961; Pandi, 2002; Stanciu et al., 2005; Arghiuş & Arghiuş, 2007; Vinet, 2007; Gaume et al. (24 authors), 2009; Pătruţ, 2010; Sarhadi et al., 2012, Cojoc et al. 2015, Zeleňáková, et al., 2017).

Satellite techniques, LIDAR, UAV or GPS have become prevailing in carrying research in the field, due to the ease, detail and speed provided, being already used to a large extent in the elaboration of the flooding maps, at small and large scale (Schumann et al., 2007; Zwenzner & Voigt, 2009; Şerban et al., 2009; Bhatt, et al., 2011; Domeneghetti et al., 2013, Șerban et al., 2016, Coveney and Roberts, 2017). Other studies are organized starting to various hydraulic models, that are constructed based on the cartographic supports or aerial images with medium or high resolution (Sanderset al., 2005; Pappenberger et al., 2006; Neal et al., 2007; Vanderkimpenet al., 2009; Chevereşan, 2011; Altarejos-Garcia, et al., 2012; Dutta, et al., 2013, Șerban et al., 2016).

The current trends seem to guide the research on water courses with torrential character, commonly with drainage basins less than 100 km^2, which, together with rivers that are already known for generating floods, put all the largest and most common problems to human communities, whse habitat lies in their vicinity (Arghiuş, 2007; Șerban et al., 2013, Șerban et al., 2016 etc.). The smaller size (UAV) aircrafts have a serious contribution to this type of research, as it ensures independence, ease of operation, very good accuracy, if they are equipped and properly calibrated, and allow significantly the reduction of the working time (Ellum & El-Sheimy, 2006; Gerke, 2008; Kerle et al., 2008; Choi, et al., 2009; Roeoesli, 2009; Sauerbier, 2009).

The use of obtained high-resolution terrain models, correlated with accurate hydraulic calculations, allows the elaboration of flooding maps for areas with high degree of vulnerability to flooding and with limited accessibility. Also, having many flights during flooding periods facilitates a better monitoring of the flooded areas and making decisions for the optimal management of the post inundation phenomenon (Horritt and Bates, 2002, Merwade et. al., 2008, Hervouet et al., 2011, Taubenbock et al., 2011, Abdelkader et al., 2013, Abdelkader et al., 2014).

Natural and anthropogenic conditions related to the studied territory

Ozana hydrographic basin is located within the Neamt County - Moldavia Region, Romania and overlaps the relief unit represented by the Ozana-Topolița (Neamț) Depression. Its upper sector has developed in the mountainous unit represented by Stânişoara Mountains, that are a "part of the Carpathian flysch geosyncline that evolved between Lower Cretaceous and Upper Miocene" (Fig. 1) (Ichim, 1979).

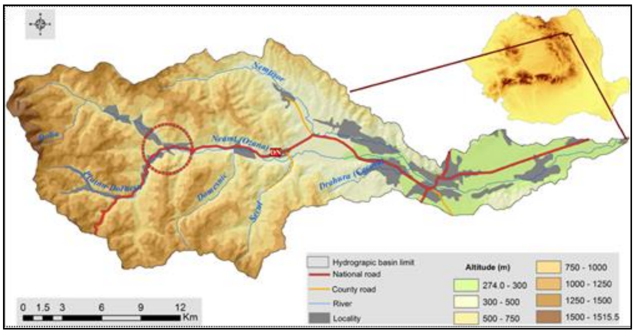

Fig. 1: The general map related to the river basin Ozana

In hydro-climatic terms, the study area is part of the Eastern Europe climate zone, since it has a transitional temperate-continental climate, characteristics that affect the eastern part of Romania, the east of the Eastern Carpathians and

Moldavian Plateau (Ștefănache 2007, Romanescu et al. 2012, quoted by Cojoc et al. 2015).

Geologically, the basin is characterized by a petrographic mosaic, crossing deposits of limestone-sandstone flysch, marls, conglomerates etc. Also, within the study area, slope values are high, the upper sectors exceeding in some parts, 25 degrees, a factor that influences the water propagation velocity. Other morphometric characteristics are given in Table 1 (Nițoaia et al., 2016).

Table 1: Some morphometric characteristics of Ozana basin (according to Romania Water Atlas, 1992, with additions)

River order	Slope (‰)	Average altitude (m)	Basin sector	Area (km^2)	Perimeter (km)	Coefficient of circularity
3	12	683	Upper	347,81	112,97	1,70
			Lower	65,66	69,7	2,42

Generally, the hydrographic basins shape, together with other morphometric characteristics, play a major role in the propagation of flash-flood waves and flood amplitude. Thus, in a basin that has an elongated shape, the concentration of water in the riverbed is more difficult than in basins with a circular, fan shape (Zăvoianu, 1978). This factor influences the magnitude of the flood waves and their effects. Also, the position of the basins in relation to the nearby mountain ranges influences the movement of air masses, and thus, the dynamic of cloud systems that generate rainfalls (Nițoaia et al., 2016).

Why Ozana hydrographic basin? After a quantitative assessment on the shape of the basin, the graphic representation of the coefficient was achieved (Fig. 2). The differences of the circularity (1.70 in the upper sector, respectively 2.42 in the lower sector), make the higher part of the studied space a torrential area, with a destructive potential at the maximum liquid flow.

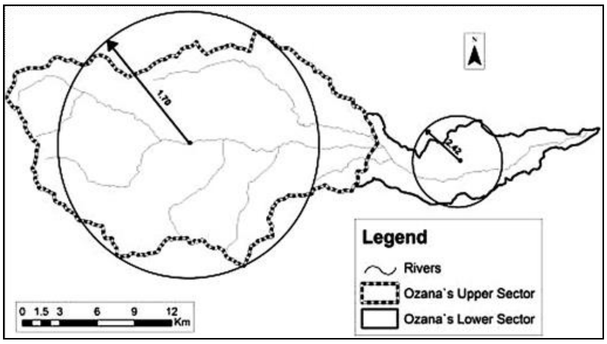

Fig. 2: Graphical representation of the coefficient of circularity for Ozana basin, created with ArcGIS 10.X's XTools Pro extension

The valley corridors are occupied by settlements, especially after the widening of the major riverbed in the lower basin (Fig. 1). These localities constitute the components of vulnerability to flood, in the case of the dangerous weather events occurrence, with the generation of significant amounts of rainfall.

Methods and results

For this study, a prior analysis of detailed cartographic materials (topographic maps 1:5000, aerial photos etc.) was done.

The photogrammetric measurements were performed with Phantom 4 quadcopter UAV technics, in the context of a UAS (Unmanned Aircraft System) work specific technology, which includes the UAV, the ground-based controller and a system of communications between the two. The measurements were aimed at achieving a digital terrain model at a centimetre resolution, in order to develop, as true as possible, the flood prone area. In parallel with the photogrammetric measurements, a topographic survey with Leica total station for the validation of the results was done.

The UAV technique used (Fig. 3) has the following features and amenities:

AIRCRAFT	PHANTOM 4 PRO
Product Position	Entry-Level Professional Drone with Powerful Obstacle Avoidance
Weight (Battery & Propellers Included)	1388 g
Max Flight Time	Approx. 30 minutes
Vision System	Forward Vision SystemBackward Vision SystemDownward Vision System
Obstacle Sensing	Front & Rear Obstacle Avoidance Left & Right Infrared Obstacle Avoidance
Camera Sensor	1” CMOSEffective pixels: 20 M
Max. Video Recording Resolution	4K 60p
Max Transmission Distance	FCC: 4.3 mi
Video Transmission System	Lightbridge
Operating Frequency	2.4 GHz/5.8 GHz
	*5.8 GHz transmission is not available in some regions due to local regulations.

Fig. 3: The Phantom 4 quadcopter used during the measurements (according to *DJI*, 2017)

Drone intrinsic parameters control is provided by the DJI-Go4 "mother" app. Before initializing any flight, it is mandatory to preliminary verify the aircraft status (sensors, batteries charge status, camera settings etc.).

Route defining and drone control has been made using the DroneDeploy app, installed on a HTC phone terminal which uses Android OS (Fig. 4), aiming at an optimal coverage of the proposed survey area.

Initially, the area of interest was established (Fig. 4.1), subsequently choosing the points of inflection from the flight route, for a good insurance of the necessary overlapping percent of the resulting images (Fig. 4.2); afterwards, the flight parameters were set (Fig. 4.3), for a maximum efficiency and a resolution of the images that make it possible to obtain a DSM (Digital Surface Model) with a centimetrec resolution.

Once the necessary data were obtained, these were loaded as input parameters in the DroneDeploy app, after which it proceeded to load the flight mission and conducting it. Subsequently, 720 scenes were retained and used, which have complied with the pre-calculated resulting parameters.

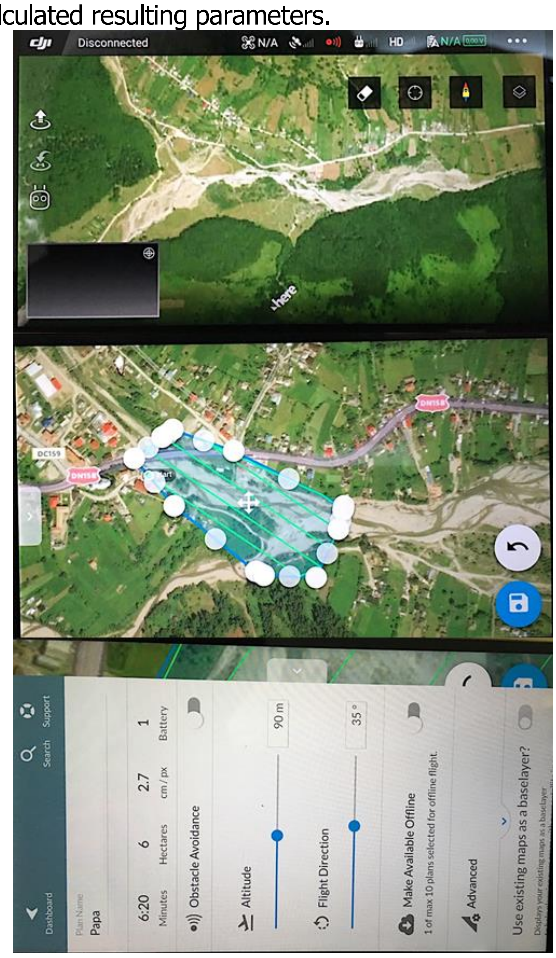

Fig. 4: Drone route configuring and manoeuvring (according to DroneDeploy: Powerful Drone & UAV Mapping Software, 2017)

Primary processing, in order to obtain quantitative data on the route and flight parameters was performed using UAVPhoto 1.0.0.2 app. This open-source app has allowed the ante-calculating of parameters such as: the pixel size of concerned land unit; the blur motion parameter; the velocity and the altitude; focal length of the camera; the used corresponding aperture etc. and ensuring of an overlapping of 80% on the Y-axis and respectively of 60% on the X-axis.

Further, the Visual-SFM open-source was used for information processing; Daisy algorithm was the mathematical algorithm used for determining the nodal points of aerial micro-triangulation network (Tola et al. 2010). It is based on the (logical) conception shown in figure 5.

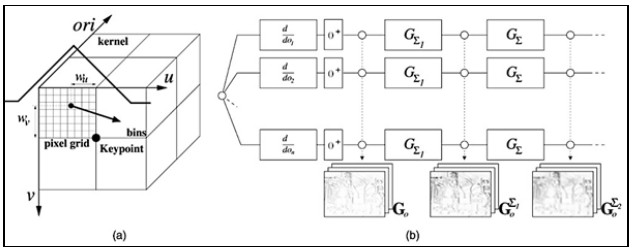

Fig. 5: Daisy mathematical algorithm concept (after Tola et al. 2010)

The nodal points of aerial micro-triangulation network, used for the 3D scene recomposition, are analysed on the basis of proximity and, in this way, the pairs of identical pixels are automatically determined, thus yielding the (mesh) micro-triangulation network.

From this network, it could proceed to the development of textures (Fig. 6), the stage where it has been possible to bind information (held in local coordinates), to the Stereo 70 real coordinates system (assuming the procedures of internal and external orientation established by classical photogrammetry).

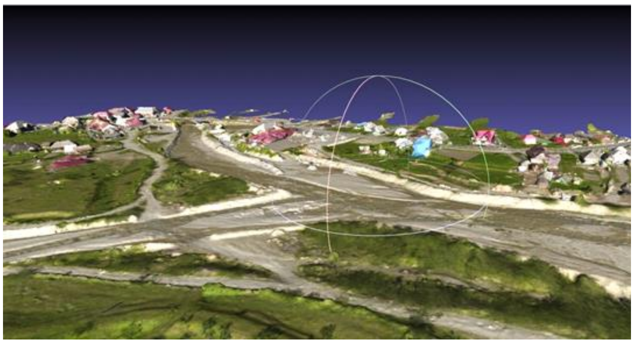

Fig. 6: The work surface textures exportable in the orthophotoplan

The emerged composite picture is one of high resolution (Fig. 7), which made possible the high detail export of the numerical model of the land (DSM) (Fig. 8).

For processing of flow rates statistical data, the programs Microsoft Excel and Hyfran were used.

Flows with exceeding probability used in the hydraulic calculation, were: $Q_{1\%}$ river Ozana, Leghin hydrometric station = 380 m^3/s and $Q_{1\%}$ river Pluton-Dolhești, Dolhești hydrometric station = 90 m^3/s. These values have been obtained in the section of gauging stations, on the basis of the observation data, using two theoretical distributions (Kriţki-Menkel and Pearson III) and was extrapolated at the actual measuring sections.

These are the generalized gamma distribution and are two of the most popular distributions for hydrologic frequency analysis (Constantinescu et al., 1956; Bobee, 1975; Diaconu and Şerban, 1994).

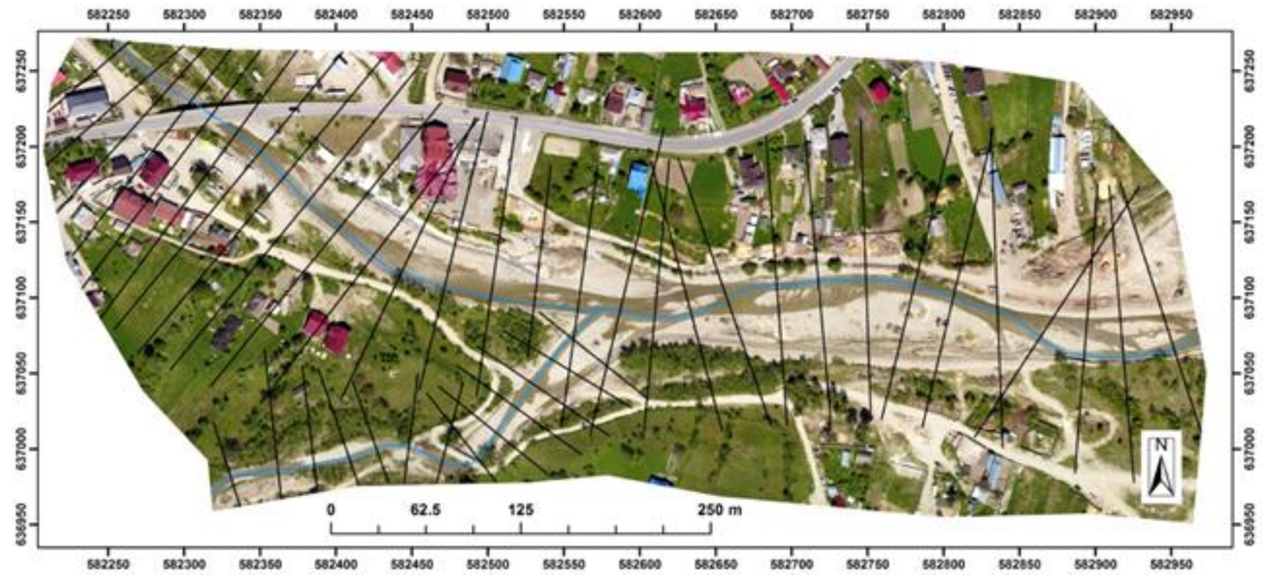

Fig. 7: The composite aerial image of the study area, with the profiles for the hydraulic calculation

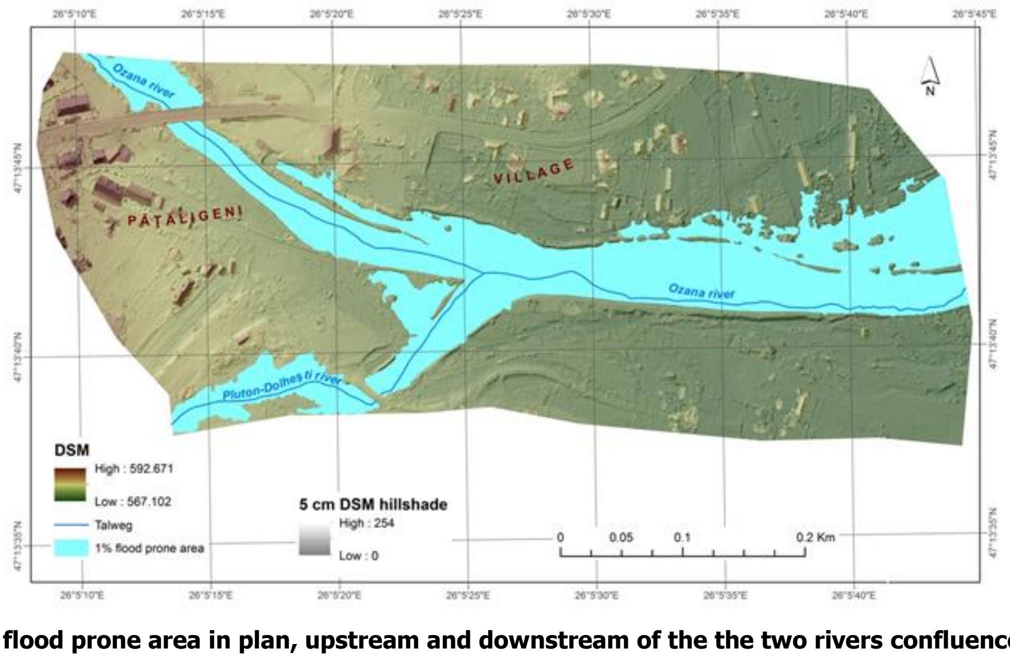

Fig. 8: 1% flood prone area in plan, upstream and downstream of the the two rivers confluence, overlapped on the high-resolution DSM

In the ArcMap 10.x module, on the altitude grid support, we proceeded to the extraction of 43 cross profiles, at a maximum distance of 30 meters between them, for an accuracy similar to the interpolation of flood prone areas.

These profiles have been georeferenced, in the first phase, in local coordinates, for performing to the real scale of the hydraulic calculations, regarding the surface of the cross-section Ω (m^2) and the maximum water depth on the profile, h_{max} (m).

The average velocity V_m (m/s) of water in the 43 sections have been determined on the basis of Manning formula:

$$V_m = \eta^{-1} * R^{0,67} * I^{\ 0,50}$$

where: V_m - average speed of water current (m^3/s);

η – the coefficient of roughness;

R – hydraulic radius (m);

I – slope at the level of the water surface (m/m).

In the second phase, the hydraulic radius R (m) was considered to be 0.9 of the average depth h_{med} (m) on the profile. The hydraulic slope (m/m) was topometrical determined in the field, and the η coefficient from the tables.

The georeferencing of the cross profiles, where the water level was marked at 1% probability of flow, in the projection system Stereo 70 and overlapping them over the grid elevation support constituted the last steps before the delimitation of the flood prone areas for the referred probability (Şerban et al., 2016).

The polygon of effective flood prone area has been obtained by graphic interpolation of in ArcMap between the ends of the cross profiles, according to the elevation grid slope (Fig. 8).

Discussions

After overlapping the flood prone area on the ortophotoplan of the study area, it is observed that the population and local authorities have learned from past experience and they proceeded to a precautionary location/relocation of households and properties (Fig. 9).

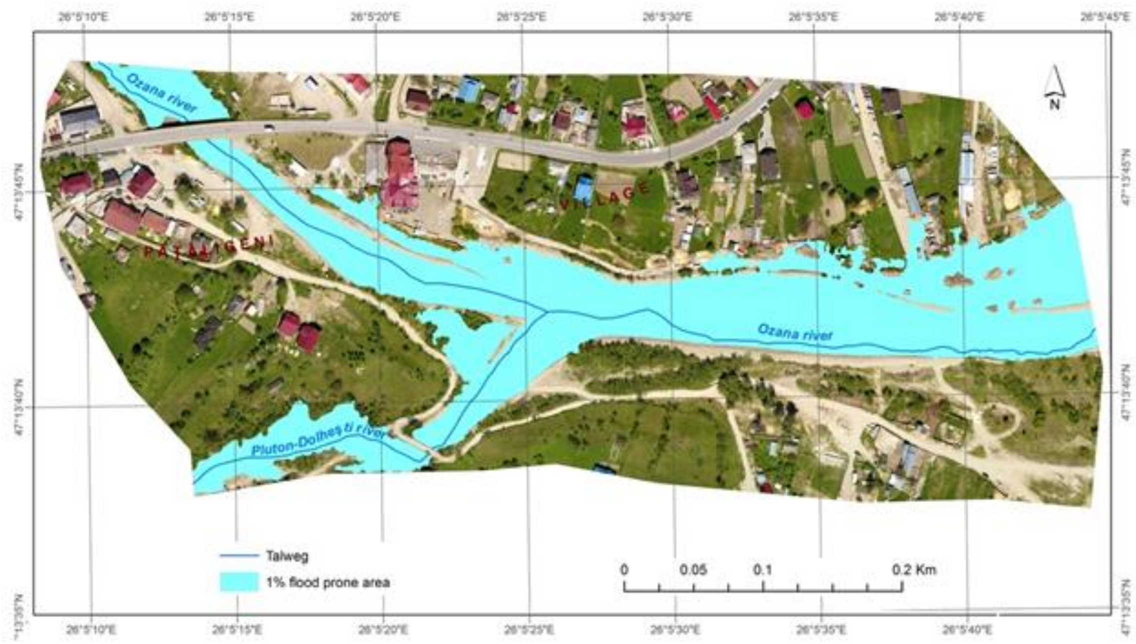

Fig. 9: 1% flood prone area in plan overlapped on the composite orthophotoplan

Few of these households are located within the flood vulnerable area, although the two water courses have a torrential character, and sedimentary petrographic deposits from basin (Carpathian flysch) provide significant quantities of alluvia; this material clogs/remodels in a consistent mode the floodplain at each important flood.

The authorities, which manage the water courses from the basin ("Siret" Water Basin Administration) have intervened wtithin the riverbed, recalibrating it. Following this calibration, most of the flows with low probability pose no threat, without large-scale overflows at maximum flow phase - like flash flood type. Such actions must be periodically repeated, whereas the clogging of the minor riverbed is particularly accelerated.

With respect to the UAS system that was used, there is an increased reliability, compared of the techniques of the older generation; this is possible due to to the preliminary configuration permissiveness of the route and of the overflight area, as well as self-mobilization of the aircraft, which is also, latest technology.

It should be noticed the drone increased autonomy, as well as the better performance of the built-in camera, able to orient themselves during the flight, under more difficult aerial conditions.

The resulting aerial images have a very good chromatic and resolution, and their processing allows the development of ultra-high definition DSM models, of great value in the floodable areas analysis, especially of the minor and major riverbeds.

The speed of land measurement achieving is increased, as compared with the classic topometric measurements or to those with GPS terminal; also, the density of reading of the land surface is the quasi-total.

Conclusions

Testing of new generation of flying machines remotely controlled brings substantial improvements in aerial photography and derived topography surface modelling. The application of the technique and of the new UAS system in the flood prone area study, particularly in the cvasi-circular basins with high torrents offers a higher efficiency for carrying measurements and also encourages a higher frequency of their use, due to the optimization of any work stages.

The improved resolution following the achievement of the DSM allows the study and great detailed modelling of all surfaces located within vulnerable areas, including those of great interest, such as the civil or private objectives, of great economic or cultural value.

The advantages of using this technology are:

- this leads to increasing the autonomy of work and the coverage of a more extensive area on a single flight;
- the 3D reconstruction process based on UAV technology (drone) and on the "Daisy" interpolation algorithm is cheap, relying on open-source solutions;
- the accuracy of the reconstruction 3D (5cm, in this case) is much higher than the traditional aerial surveys;
- the final product (DSM, orthophoto) can be georeferenced in general interest coordinates, overlaid on any data bases brought into the same projection system and integrated in any GIS or CAD type application;
- the procedure allows the rigorous qualitative and the quantitative approach (distances, surfaces, volumes), given the details that the modelling has been done;
- the procedure is non-invasive and is applicable in areas difficult to reach or inaccessible by traditional technology.

Some disadvantages of the application of the technology must also be mentioned:

- the flight is irrelevant if the surveyed area is covered by snow;
- it is recommended the flight should take place during spring, before the vegetation blooms, because this brings a serious shielding and numerous errors in data processing;
- the flight cannot be executed if wind velocity exceeds 60 km/h or there is unfavourable light; in this case, the flight was performed during the calm weather;
- the autonomy of a flight is relatively low and reported to a battery unit (normally, under 40 minutes), to avoid the collapse of the system and the recording significant damages;
- the low temperature in the flight environment is greatly impinging on the mission, causing a quick consumption of the battery;
- important hardware resources are required for data processing; in the present case, a PC with Intel i7 processor, 16 GB of RAM memory, 4 GB of video memory card on GDDR 5 GHz, and a 256 GB SSD was used.

Identifying areas with high risk to flooding, particularly in the cvasi-circular basins with high torrents can contribute to the sustainable development of settlements through the reduction of potential damages. The performed studies allow the imposition of restrictions regarding the location of the various objectives in these areas.

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