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ESTIMATION OF FLOW VELOCITY DURING FLASH FLOODS WITH THE SYNERGY OF UNMANNED AERIAL SYSTEMS (UAS) DATA AND GROUND OBSERVATIONS: THE CASE OF 2017 MANDRA FLASH FLOOD, GREECE

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Abstract

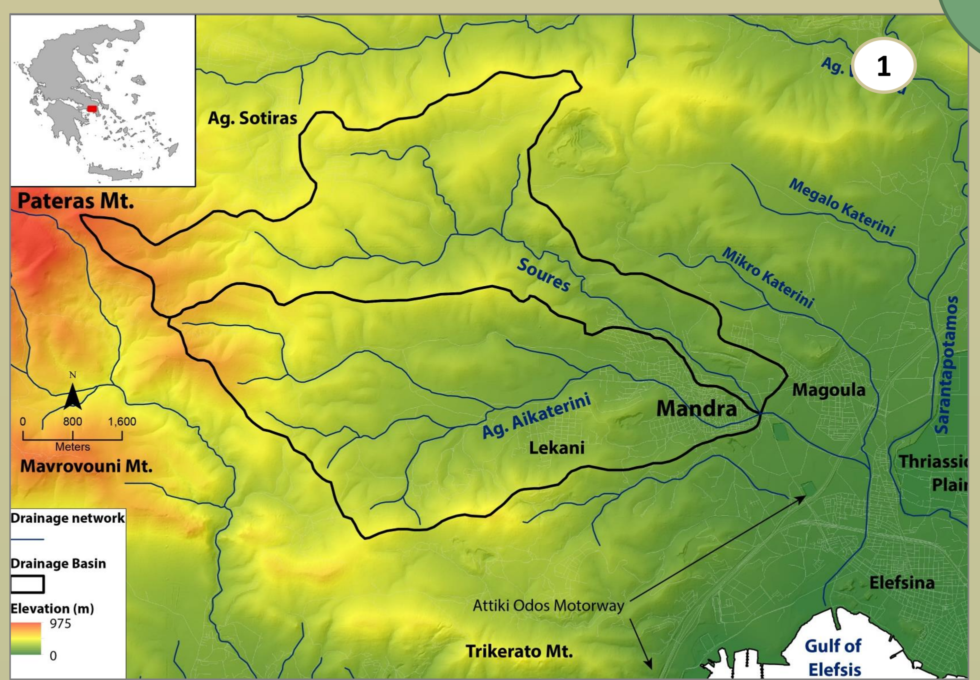
Unmanned Aircraft Systems (UAS) can be used to enhance monitoring of a wide range of environmental parameters, including acquiring data on various types of hydro-geomorphic phenomena.

Their capabilities to provide on-demand images and videos of high resolution are particularly useful in the case of flash flood phenomena, which occur in spatial and temporal scales that do not favor traditional monitoring processes.

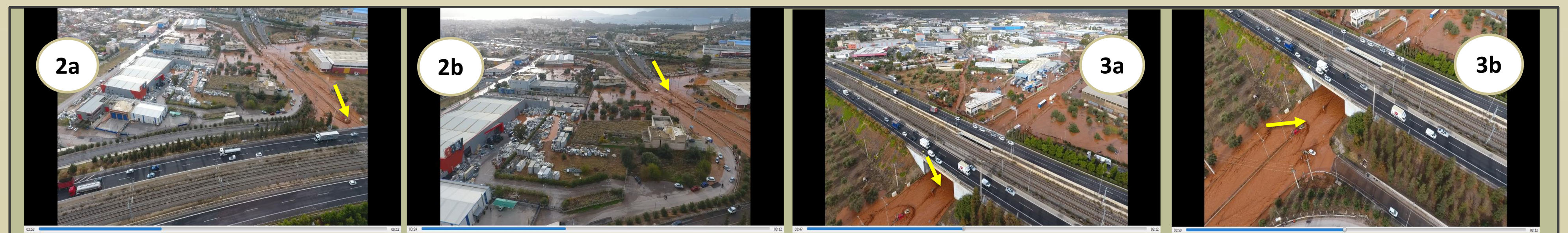
n this work, flow velocity is estimated using aerial imaging acquired by means of an Unmanned Aircraft Vehicle (UAV) as well as ground observations during the catastrophic flash flood event of November 2017 in Mandra, Greece.

In these imaging detailed tracing of various floating objects and particles such as light trash, debris, etc. was carried out using multiple high-resolution video frames with specific time marks. Water velocity estimations were also cross-examined using flood mark-derived velocity hydraulic heads extracted by ground observations after the flood.

The analysis was applied at a variety of locations across the study area, leading to a map of velocities for parts of the floodplain. Velocity values varied significantly depending on location, reaching up to 10m/s.



Methodology

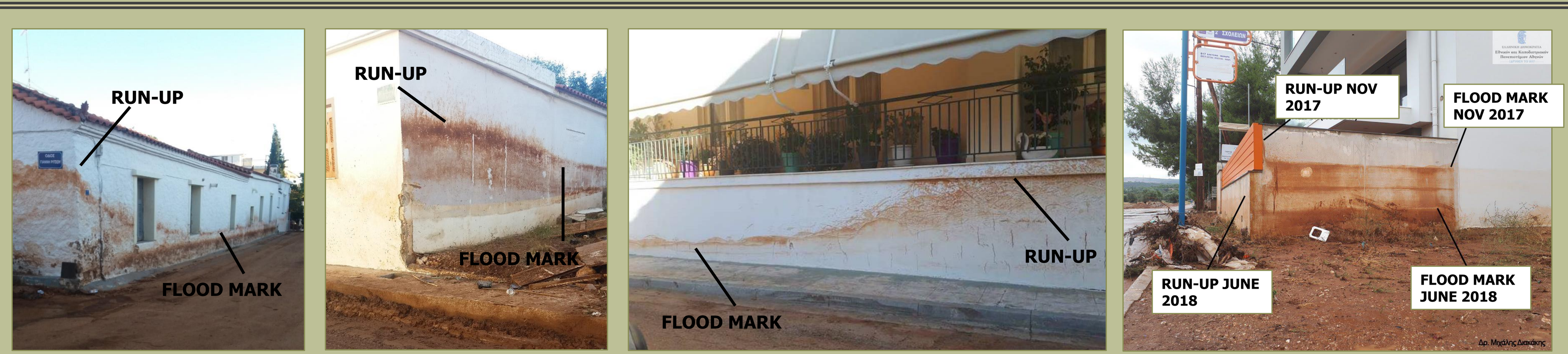


Video snapshots were collected using UAS imagery at the starting point of the obstacle like the example of images 2a, 3a, and at the final point like 2b, 3b. The obstacles were georeferenced as shown on images 4 and 5 which correspond to images 2a, 2b, and 3a, 3b respectively. The measurements were carried out by two researchers to assess the mean velocity during the flash flood as for the results be confirmed.

Table 1: Database of measurements to assess the mean velocity in GIS ArcMap environment.

Table
Velocity Range

FID	Shape *	ID	Seconds	Distance1	Velocity1	Distance2	Velocity2	MeanVel	Vel1_2
0	Point ZM	1	35	19,7	0,5	19,7	0,5	0,5	1
1	Point ZM	2	51	45	0,8	44,9	0,8	0,8	1,6
2	Point ZM	3	64	67,2	1	66,9	1	1	2
3	Point ZM	4	31	125	4	124,6	4	4	8
4	Point ZM	5	3	16	5,3	15,9	5,3	5,3	10,6
5	Point ZM	6	2	13,9	6,9	13,4	6,7	6,8	13,6
6	Point ZM	7	23	25,7	1,1	25,3	1,1	1,1	2,2
7	Point ZM	8	14	11,6	0,8	11,4	0,8	0,8	1,6
8	Point ZM	9	6	6,1	1	6	1	1	2
9	Point ZM	10	8	37,9	4,7	37,6	4,7	4,7	9,4
10	Point ZM	11	3	20,8	6,9	20,7	6,9	6,9	13,8
11	Point ZM	12	5	44,3	8,8	44	8,8	8,8	17,6
12	Point ZM	13	7	32,5	4,6	32,3	4,6	4,6	9,2
13	Point ZM	14	4	14,7	3,6	14,5	3,6	3,6	7,2
14	Point ZM	15	4	23,8	5,9	23,8	5,9	5,9	11,8
15	Point ZM	16	10	28,9	2,8	28,6	2,8	2,8	5,6
16	Point ZM	17	2	7,6	3,8	7,7	3,8	3,8	7,6
17	Point ZM	18	9	15,8	1,7	15,8	1,7	1,7	3,4
18	Point ZM	19	27	117,6	4,3	117,2	4,3	4,3	8,6
19	Point ZM	20	2	7,8	3,9	7,9	3,9	3,9	7,8
20	Point ZM	21	21	23,2	1,1	23,7	1,1	1,1	2,2
21	Point ZM	22	18	5,7	0,3	5,3	0,2	0,2	0,5
22	Point ZM	23	4	23	5,7	23,5	5,8	5,7	11,5



On these images, superelevations in front of obstacles located in the flow as walls, bridges, and others may be visible. This superelevation is related to the assessment of flow velocity. The application of the Bernoulli equation gives the range of possible values for this velocity, where y1 and V1 represent depth the water depth, and the mean velocity respectively in the area surrounding the obstacle, y2 represents the water depth in front of the obstacle and g = 19,62.

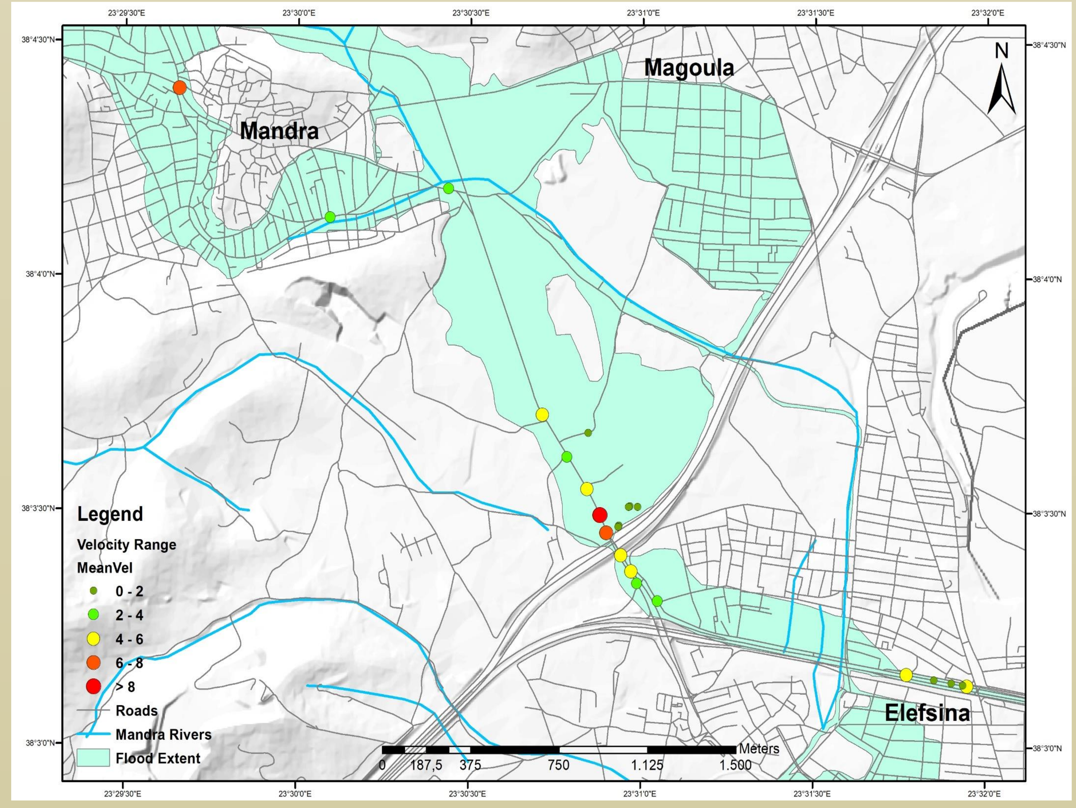
$$y_1 + \frac{V_1^2}{2g} = y_2 \Rightarrow V_1 = \sqrt{2g(y_2 - y_1)}$$

Table 2: Database of measurements to assess the mean velocity using Bernulli formula.

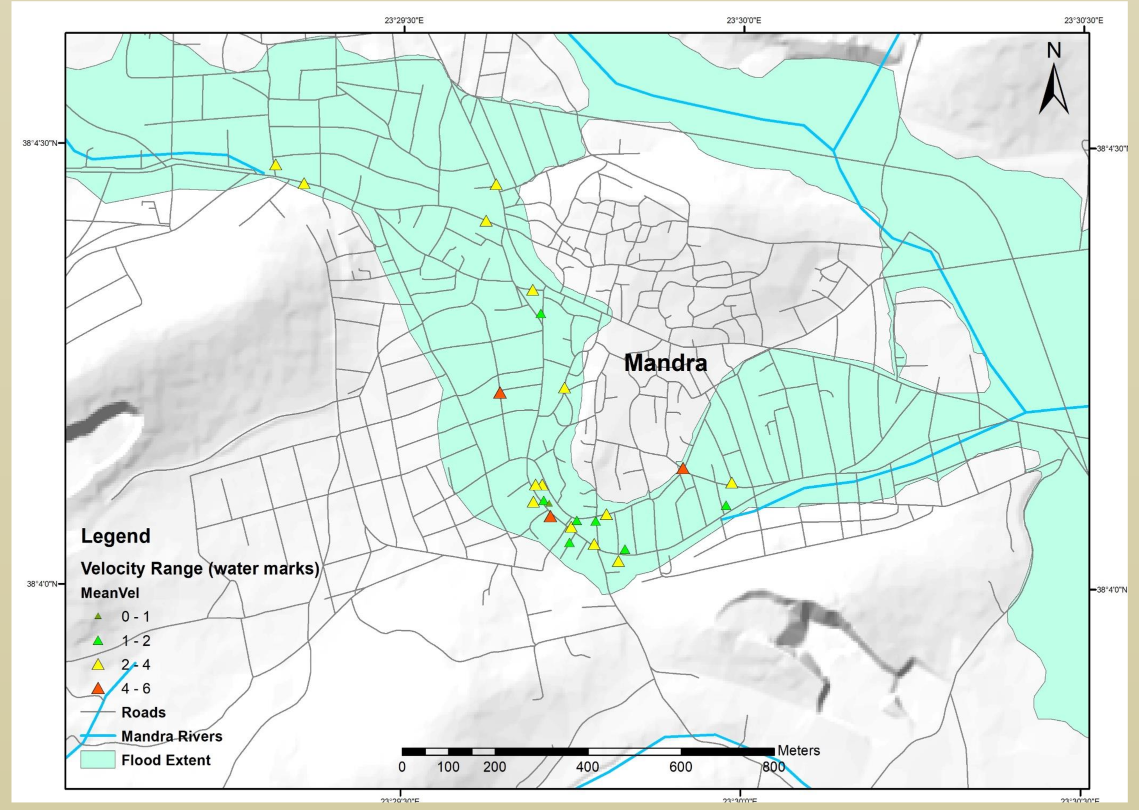
Table
Velocity Range (water marks)

FID	Shape *	ID	Height1_res1	Height2_res1	Height1_res2	Height2_res2	y2 - y1_re1	y2 - y1_res2	2g(y2 - y1)_res1	2g(y2 - y1)_res	SQRT_res1	SQRT_res2	Vel1 + Vel2	MeanVel
0	Point ZM	1	0,3	1,1	0,3	1	0,8	0,7	15,696	13,734	3,9	3,7	7,6	3,8
1	Point ZM	2	0,6	2	0,4	1,9	1,4	1,5	27,468	29,43	5,2	5,4	10,6	5,3
2	Point ZM	3	2	2,5	1,8	2,2	0,5	0,4	9,81	7,848	3,1	2,8	5,9	2,9
3	Point ZM	4	0,6	1,3	0,5	1,2	0,7	0,7	13,734	13,734	3,7	3,7	7,4	3,7
4	Point ZM	5	1,5	2,3	1,5	2,1	0,8	0,6	15,696	11,772	3,9	3,4	7,3	3,6
5	Point ZM	6	0,5	1,8	0,45	1,7	1,3	1,25	25,506	29,8224	5	5,4	10,4	5,2
6	Point ZM	7	2,3	2,5	2,1	2,4	0,2	0,3	3,924	5,886	1,9	2,4	4,3	2,1
7	Point ZM	8	2,4	2,8	2,4	2,7	0,4	0,3	7,848	5,886	2,8	2,4	5,2	2,6
8	Point ZM	9	2	2,5	1,9	2,5	0,5	0,6	9,81	11,772	3,1	3,4	6,5	3,2
9	Point ZM	10	1,6	1,8	1,6	1,9	0,2	0,3	3,924	5,886	1,9	2,4	4,3	2,1
10	Point ZM	11	2	2,5	1,9	2,2	0,5	0,3	9,81	5,886	3,1	2,4	5,5	2,7
11	Point ZM	12	2,2	4	2,1	3,8	1,8	1,7	35,316	33,354	5,9	5,7	11,6	5,8
12	Point ZM	13	1,6	1,85	1,5	1,8	0,25	0,3	4,905	5,886	2,2	2,4	4,6	2,3
13	Point ZM	14	2,8	3	2,8	2,9	0,2	0,1	3,924	1,962	1,9	1,4	3,3	1,6
14	Point ZM	15	2,2	2,4	2	2,2	0,2	0,2	3,924	3,924	1,9	1,9	3,8	1,9
15	Point ZM	16	2,2	2,4	2	2,1	0,2	0,1	3,924	1,962	1,9	1,4	3,3	1,6
16	Point ZM	17	2,3	2,5	2,1	2,4	0,2	0,3	3,924	5,886	1,9	2,4	4,3	2,1
17	Point ZM	18	1,1	1,2	1,2	1,35	0,1	0,15	1,962	2,943	1,4	1,7	3,1	1,5
18	Point ZM	19	2,1	2,4	2	2,2	0,3	0,2	5,886	3,924	2,4	1,9	4,3	2,1
19	Point ZM	20	2,5	2,6	2,6	2,7	0,1	0,1	1,962	1,962	1,4	1,4	2,8	1,4
20	Point ZM	21	1,5	1,6	1,4	1,65	0,1	0,25	1,962	4,905	1,4	2,2	3,6	1,8
21	Point ZM	22	1,1	1,3	1,2	1,4	0,2	0,2	3,924	3,924	1,9	1,9	3,8	1,9
22	Point ZM	23	1,3	1,6	1,25	1,5	0,3	0,25	5,886	4,905	2,4	2,2	4,6	2,3
23	Point ZM	24	1	1,2	1,2	1,35	0,2	0,15	3,924	2,943	1,9	1,7	3,6	1,8
24	Point ZM	25	1,4	1,6	1,3	1,6	0,2	0,3	3,924	5,886	1,9	2,4	4,3	2,1

Results and conclusions

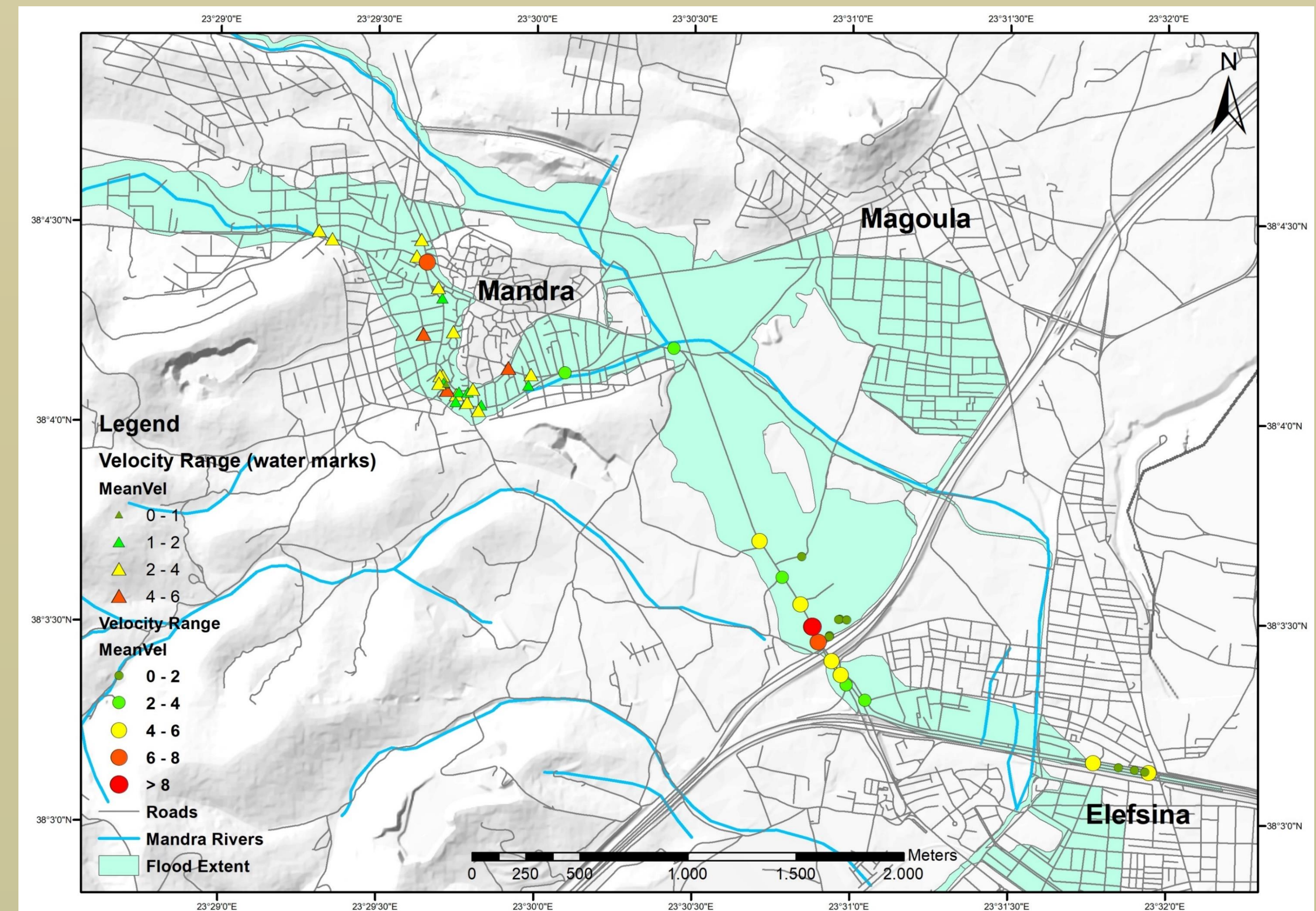


Map 1: The mean velocity derived from method 1 with mean flow velocity range from 0 up above 8m/s in Industrial Area and Old National Road mainly

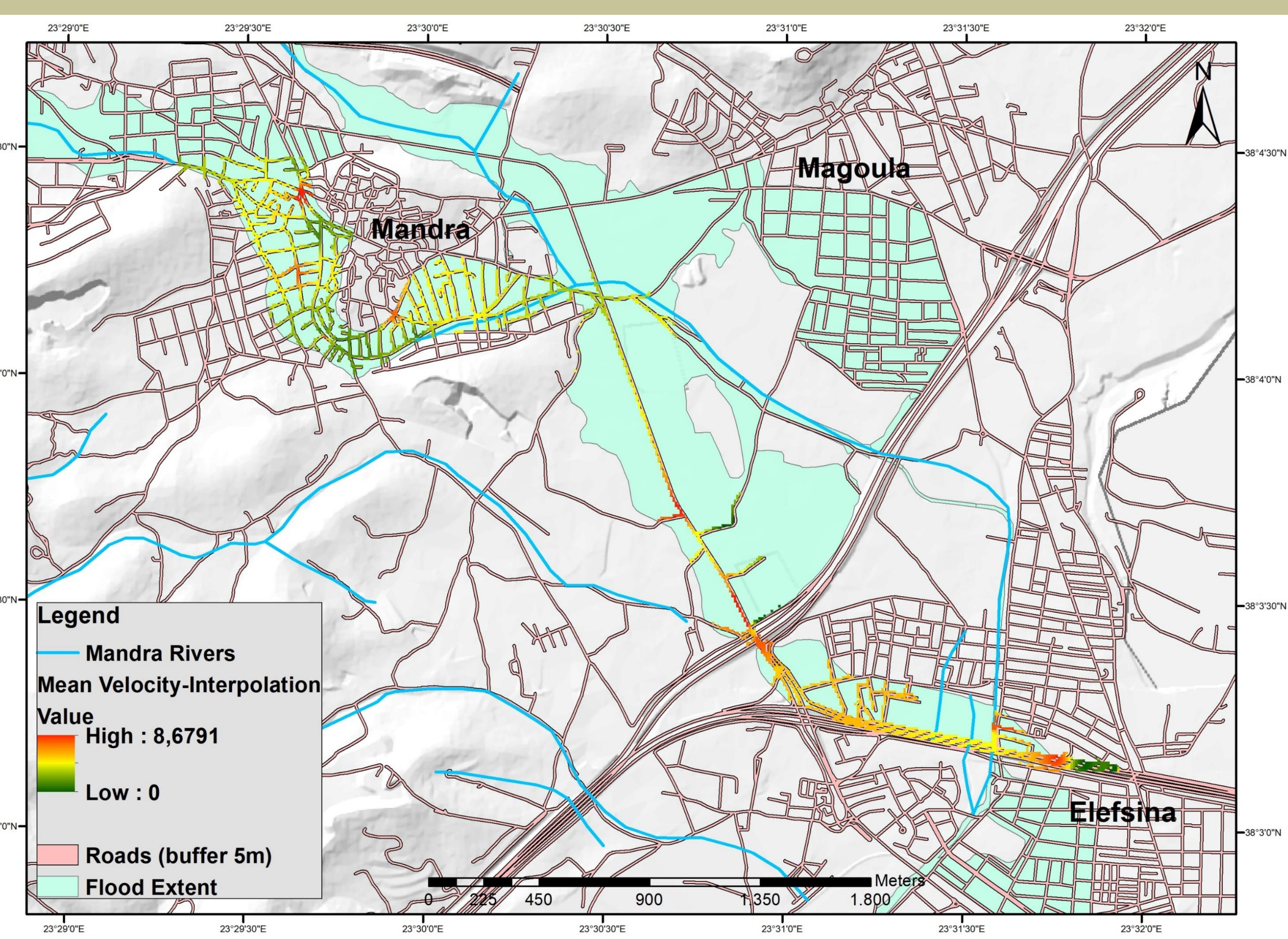


Map 2: The mean velocity derived from method 2 with mean flow velocity range from 0 to 6m/s in Mandra settlement

Map 3: The mean velocity derived from the two methods that shows the flood extent and the mean velocity values with a range from 0 to greater than 8m/s



Map 4: The interpolation of mean velocity along the roads of the region according to the values measured. Inverse Distance Weighting (IDW) interpolation was applied and estimates unknown values with specifying search distance, closest points, power setting & barriers.



Flash floods belong to one of the most serious risk damages in Europe, including Greece. The main purpose of this research is the mitigation of the risk. These floods cause crucial damage to the natural environment, building collapses, injuries, and even fatalities. During the development of the event, it is impossible to make measurements with instruments either because they can be destroyed or because they can not cover the study area. A field survey was conducted with modern and innovative techniques comprising Unmanned Aerial Systems (UAS) in during the first hours of the phenomenon. Data processing was carried out at a later time in the laboratory while complementing ground observations.

The UAS proved to be very useful for the collection of important data for an extended area during the flood since a large portion of it was inaccessible due to road closures and safety issues. Nevertheless, the approach comes with certain limitations, including flight regulations, safety precautions, and that the rainfall is at a level that allows the deployment of a UAV during a flash flood. In this research the purpose is to assess the flow velocity of the flood, using from UAS imagery data. Two different methods were used and the measurements were carried out by two researchers in order to verify the results. In the first method, various floating objects and particles such as light trash, debris, etc. (23 obstacles were detected) were traced by the examination of the UAS imagery and by using multiple high-resolution video frames with specific time marks, one at the starting georeferenced position of the object and the other one at its final georeferenced position georeferenced. In the second method, water velocity estimations were also cross-examined using flood marks derived from the velocity of hydraulic heads which was extracted by ground observations after the flood. 25 positions were detected by checking UAS videos and images, superelevations in front of the obstacles located in the flow such as walls, bridges, and others visible objects. The Bernoulli equation was applied and gave the range of possible values for the flow velocity. As a result, in the case of Mandra flash flood, the estimated mean flow velocity values have a range of 0 to 8,7m/s. According to the existing bibliography the values measured in this study are considered high (Gaume and Borga, 2008). In this study we can interpret the results on the bases of microscale determined by the characteristics of this case. Thus four classes of mean velocity values were defined. The first class includes the values with a range of 0-4m/s and characterizes low flow velocities. The second class includes the values with a range of 4-6m/s and characterizes medium flow velocities. The third class includes the values with a range of 6-8m/s and characterizes high flow velocities. The fourth class includes flow velocity up to 8m/s and characterizes very high flow velocities. Furthermore, we regard that the values belonging to the first class correspond to the values measured in narrow streets with many obstacles. the values belonging to the second class corresponds to the values measured in wide roads and to roads with only a few obstacles. The values belonging to the third class correspond to the values measured in less inhabited areas and to highways. Finally, the fourth class corresponds to the values measured in non inhabited areas and too wide highways. According to this analysis, the most velocity values belong to the second class. In our case study the flash flood is characterized by medium velocity values. The derivatives show that the combination of aerial with ground observations in post-flood analysis contributes to the completeness and the accuracy of the database regarding specific flash flood parameters. Thus, in the future databases such as this can be become a valuable source of information, especially in data-poor regions. This approach is an advantageous tool that can be useful for future plans, decisions, regarding the efficiency of the flood mitigation measures, the solutions for recovery from the floods, and the limitations of the future risks.

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