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Development of the new methodological framework for multiscale modelling of urban pluvial flooding

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Abstract—**In recent years pluvial (rain-related) floods are causing more and more damage to urban areas. In the future, an increase in ongoing urbanization and in extreme precipitation events are expected, which imposes the need to develop a comprehensive (multiscale) methodological framework that could prevent and mitigate adverse consequences of pluvial floods. In this paper, we present a new methodological framework for multiscale modeling of urban pluvial flooding developed in STREAM (*Strategic development of flood management*) project, funded by the Italy-Croatia cross-border cooperation program 2014-2020. This newly developed framework includes three levels of research (macro - meso - micro). The macro-level encompasses the catchment area of the Zadar settlement, meso-level the administrative border of the city and, the micro-level encompasses a small pilot area (<5 ha) within the Zadar. Spatial data with a resolution of several millimetres up to 60 cm will be collected and processed using a wide range of geospatial technologies. This developed multiscale framework can be considered as an important decision-support tool that can further improve existing decision practices in relation to urban drainage.**

I. Introduction and Study Area

Floods have become serious natural threats that significantly affect the economy and human lives, especially in urban areas [1-3]. Flooding of urban areas is associated with coastal [4-5], fluvial [6-7], and pluvial floods [8-9]. In recent years, pluvial floods have been considered a major threat for many cities [2,10]. Urban pluvial floods usually occur when rainfall exceeds the capacity of the stormwater drainage system [2], which usually occurs when an extremely large amount of precipitation occurs in a relatively short period of time. For example, the coastal part of Croatia recorded rainfall events with more than 200 litres of rain per square meter in less than 24 hours, while at the same time the rainfall amount and intensity were lower in the continental part [11]. There are numerous different approaches for modeling urban pluvial floods [2,12]. In the past few years, advanced 2D mathematical simulations have been developed focusing on flood simulation, runoff velocity, and intensity within the urban environments [1,3,9,10,13]. High-quality data is necessary to create high-resolution models of urban pluvial floods. By increasing the spatial resolution of input data it is possible to obtain precise flood maps [2,9,12-13]. Therefore, the Zadar pilot area is divided into three levels of research: macro, meso, and micro. The City of Zadar is located in the middle of the eastern Adriatic coast (Fig. 1). It consists of 37 local committees of which 12 are located on the islands. Research of urban pluvial floods will be carried out in the mainland area of the Zadar City, that is the settlement of Zadar. The coastal area of Zadar is exposed to storm surges due to low relief while the rest of the city is vulnerable to frequent pluvial floods caused by a large catchment area, a high percentage of impermeable surfaces, and a poor drainage system. Additionally, the frequency and intensity of rainfall are expected to increase in the future as a result of climate change [14-15]. The most significant flood event in the past few decades occurred on September 11, 2017, when about 285 mm of rain fell on the city area within 24 hours. A thunderstorm resulted in torrential floods and caused significant material damage (Fig. 2). Earlier, a similar event was recorded on the same date in 1986, when 352.2 mm of rainfall was recorded in the 24-hour period [16-17].

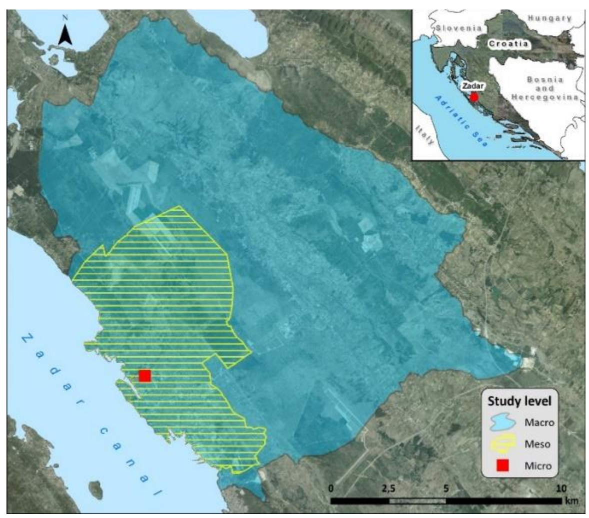

Figure 1. Research levels of Zadar pilot area.

Figure 2. Consequences of the catastrophic flood event in Zadar 9/11/2017.

II. MATERIALS AND METHODS

The macro-level of research encompasses the catchment area of the Zadar settlement (Fig. 1). At this level of the research, surface elevation data will be collected by photogrammetric restitution (by *State Geodetic Administration* – SGA) and used to create a digital terrain model (DTM). The most suitable interpolation method will be selected by evaluating various geostatistic and deterministic interpolation methods [18-19]. Spatial resolution will be determined considering the number of samples and size of the research area [20-21]. Furthermore, satellite imagery (Sentinel 2) with a spatial resolution of 10 m will be used to create a land cover model (LCM) using GEOBIA (*Geographic Object-Based Image Analysis*) methodology [22-25]. Segmentation parameters and optimal classifier will be determined by classification accuracy assessment of several most used classifiers [26-28]. LCM and derived parameters from DTM will be used for more accurate modeling of surface flows considering absorption characteristics of different soil types. Furthermore, data from the *Central Register of Spatial Units* (CRSU) (roads and facilities) as well as the updated data from the meso level of research will be used for generating flood sensitivity, vulnerability, hazard, and risk maps. The aim of this research level is to obtain information about the general hydrological characteristics (slope, imperviousness, infiltration, roughness, etc.) of the Zadar catchment area (Fig. 3A).

The meso level of research encompasses the administrative border of the Zadar settlement (Fig. 1). At this level, aerial photogrammetric data (RGB + infrared (IR)) from the SGA will be used to create a digital surface model (DSM), DTM and LCM with a spatial resolution of 60 cm. Segmentation parameters and optimal classifier for LCM will be determined using the same scientific methods as at the macro-level of research. Furthermore, CRSU data (roads and facilities) will be updated with detailed facility and population data that will be acquired from different sources (open-source data, field survey, Croatian Bureau of Statistics (CBS) etc.). The modified dataset will be used for the assessment of the flood sensitivity and vulnerability maps, as well as the flood hazard and flood risk maps. Communal infrastructure data (manholes, pipe flows, drainage systems, wastewater plants, etc.) will be collected from the local municipalities, public utility companies and field surveys in order to develop high-quality input data and support pluvial flood modeling. These data will be used on all three study levels. The goals of this research are to (1) obtain information about a detailed hydrological characteristic within the catchment - settlement of Zadar; (2) define the most flood-prone (vulnerable) location to pluvial floods, using GIS-MCDA (*Multi-criteria Decision Analysis*). The latter will be studied in more detail at the micro-level of this research.

The micro-level of the research will encompass a small pilot area within the Zadar settlement with a total area of up to 5 ha (an urban block sub-catchment) (Fig. 1). Within the defined test area, aerial photogrammetric (RGB and multispectral images (MS)), Terrestrial Laser System (TLS), and Aero Laser System (ALS) data all with a spatial resolution of 5 cm will be conducted. These high-resolution data will be used to create DSM, 3D city model and, LCM. Within the GEOBIA process, segmentation parameters and optimal classifier for LCM will be determined using the above-mentioned scientific methods. Updated CRSU data from meso level as well as underground and aboveground communal infrastructure data will also be used. The stormwater drainage system data will be updated and precisely located using Ground-penetrating radar (GPR) technology. Furthermore, specialized radars for the detection and quantification of stream floods will be installed at specific locations. Also, advanced pan-tilt-zoom (PTZ) cameras will be mounted along the roads to count people and different vehicle types. Within the selected test area, at several specific locations, physio-chemical analysis of the stormwater's quality will be examined using a multiparameter sonde. The sonde will provide information on the pH value, turbidity, nutrients, and heavy metals of the stormwater. The aim of this research is to determine which amount of runoff is affected by wastewater and other pollutants. Research goals at the micro-level are to perform detailed analysis and obtain very-high quality information of the hydrological processes within the most flood-prone location within Zadar and to propose "smart" solutions (such as *Sustainable Urban Drainage Systems* – SUDS) to mitigate pluvial floods and reduce its negative effects on the environment. Depending on the study area location and analyzed flood type, a multibeam echosounder (MBES), thermal camera, and non-contact water level sensors will be used to collect additional data (depth, temperature, sea-level fluctuations, etc.) to generate higher quality models. Potentially, a 3D scanner will be used to scan the morphology of roads and shafts to get a better insight into the runoff at the sub-micro level (Fig. 3C).

III. RESULTS AND CONCLUSIONS

The main purpose of pluvial flood modeling in urban areas is to obtain results for the preparation of flood hazard maps, which will be used to prepare flood risk maps. Flood hazard maps will be derived for three scenarios, as defined by the [29]. Floods with a low probability, or extreme event scenarios (100yr return period); floods with a medium probability (20yr return period); floods with a high probability (5yr return period). For each scenario referred to above, the following elements will be computed and illustrated on a flood hazard map: the spatial flood extent; water depths or water surface elevation; flow velocity or the relevant water flow.

Pluvial floods in urban areas will be simulated by a 2D hydraulic model at all three levels – macro, meso, and micro. To accurately capture all relevant physical processes of pluvial flood flows in an urban environment, the hydraulic model will be robust and based on full shallow water equations. Additionally, the simulations will be based on 2D unsteady flow. The hydraulic model will have sub-grid bathymetry to include irregular bathymetry at each computational cell. In this way, a high-resolution DSM can be incorporated into a computational model while using a larger cell size to keep reasonable computational times.

Furthermore, the hydraulic model will have the option to account for spatially and temporally variable rainfall and spatially variable infiltration. For the reasons stated above, the pluvial flood modeling will be performed by HEC-RAS 6.0 model, which has all the required characteristics.

Considering that pluvial floods are generated by extreme rainfalls, special attention will be placed on the selection of appropriate design storm to describe a synthetic hyetograph [30]. For this purpose, several approaches will be considered at the pilot site, including the alternating block method, Euler type II, Huff curves, and the average variability method. All four design approaches will be compared to historical rainfalls and the most suitable one will be selected for flood hazard analysis. Furthermore, in addition to synthetic hyetographs, several historical rainstorms will be considered for validation purposes.

The modeling domain will be defined by DSM and spatial distribution of impervious surfaces, where pervious surfaces will have infiltration capability defined by the SCS method or the Green and Ampt method. Furthermore, based on the land cover and infrastructure data, the spatial distribution of surface roughness will be defined by Manning's roughness coefficient.

Once all the simulations and scenarios are completed, the hydraulic results (spatial extent, water depths, water velocities) will be exported to a GIS environment and flood hazard and flood risk maps will be prepared (Fig. 3D).

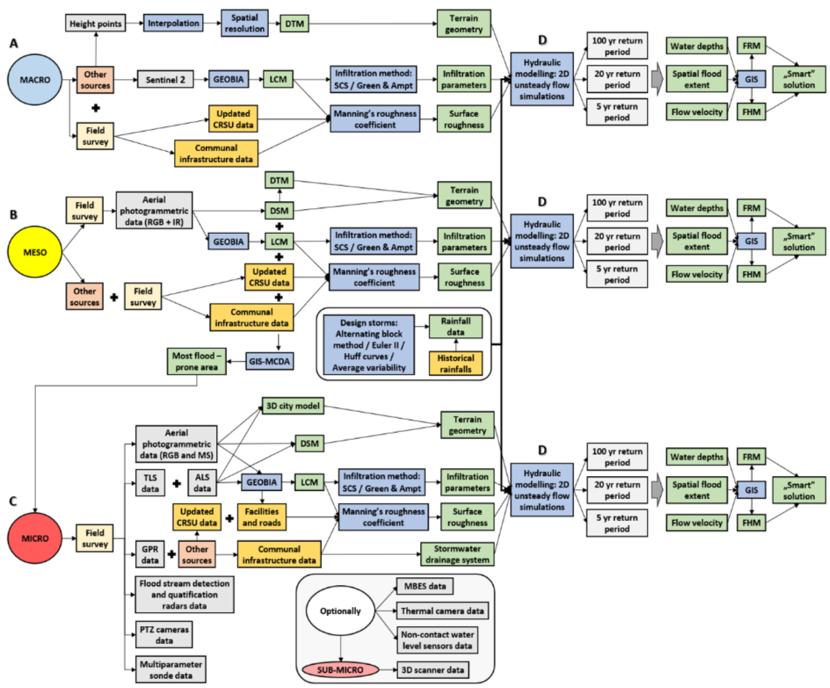

Figure 3. Methodological framework for modelling urban pluvial floods

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