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Detailed topographic data for hydraulic modeling of floodplain in urbanized areas

Vesela Stoyanova*

National Institute of Meteorology and Hydrology
66 Tsarigradsko shose Blvd., 1784 Sofia, Bulgaria

Abstract. Floods are a major problem all over the world and there is a growing concern about their relationship with climate change, engineering works and floodplain land use. The use of hydraulic models for the analysis of flood events dates to the 60s, but, until the last decade, practical applications were limited by the scarcity of detailed topographic data and the high demand of computation resources required by more complex hydraulic models. Such a situation radically changed in recent years thanks to the advances in computational resources and the availability of new topographic data sources, such as laser altimetry (e.g. LiDAR) and aerial photogrammetry. This paper explores the potential of the new method of remote sensing techniques such as DRONE to generate a high-resolution digital surface model (DSM) from aerial images for 2D hydraulic models. The information needed to create the mesh in this model is considered, and methods and approaches for collecting this information are presented. Detailed description of the Drone survey method, and processing of digital information from it to create Digital Surface Models and Digital Elevation Models.

Keywords: Geodetic survey, GIS, DEM, DSM, Drone

1. INTRODUCTION

Floods are among the most common and most dangerous natural disasters on Earth. Death tolls have increased in recent decades to hundreds of people a year. The magnitude and frequency of floods are likely to increase in the future as a result of climate change.

Within the European Union, Flood Directive 2007/60 / EC is in place, with the aim to reduce the risk of floods on Europe territory. This Directive assigns the requirement for the Member States to develop a preliminary flood risk assessment and for the areas with significant flood risk to prepare flood hazard and flood risk maps. In order to draw

* vesela.popova@meteo.bg

up such maps for the areas under threat and risk of flooding in Bulgaria, a methodology was developed by the National Institute of Meteorology and Hydrology.

The flood hazard maps are prepared following hydrological analysis and hydraulic modeling. The process of creating flood hazard maps includes the following steps: The first step is hydrological studies to estimate discharges for specific return periods. The next step is determining the corresponding water levels using 1D or 2D hydraulic models. In the third step water levels from the hydraulic modeling are used to create a grid of water surface. The water surface is compared with Digital Elevation Model (DEM) or Digital Surface Models (DSM) and the result is a Flood hazard map (Balabanova et al., 2011).

Some of the most important data for obtaining accurate flood hazard maps is data that describes the terrain. The capabilities of today's technologies to get DEM and DSM with accuracy a few centimeters are of great significance for the development of science. The variety of methods and technologies for obtaining DEM and DSM allows us to compare the results of different methods and choose the best of them for our purposes.

2. DEM AND DSM USING DIFFERENT METHODS

To begin with, what is the difference between DEM and DSM?

Both DEM and DSM are a digital representation of three-dimensional information with X, Y and Z coordinates of the continuous topography of the earth surface in a particular reference coordinate system. The difference is that DEM presents bare ground surface, while DSM captures the natural and manmade features on the earth surface.

Creating a correct DEM and DSM is critical for obtaining accurate flood hazard maps. For the development of a hydraulic model for the pilot area, first, a survey was made of the methods for the creation of DEM and DSM.

Digitization of topographic maps in different scales (Figure 1). This method is easily accessible, but it naturally has its drawbacks. It is extremely labor-intensive, the accuracy of DEM depends on the scale of the map, etc. As an example, it can be stated that for maps in scale 1: 25000 the horizontal accuracy is 10 m and the vertical 5 m. A problem with the use of digitized information from contour maps is to obtain information in very flat parts where the horizons are at a great distance from each other. Another problem is that some maps are not very good printed and there is a shuffle of layers. Maps have a different year of issue and there is a difference in height systems. One of the biggest problems is the georeferencing.

When creating DEM over small area, it is possible to survey a number of points using a theodolite or a total station. The survey network of points with coordinates is processed in a GIS environment to obtain DEM or DSM. This method is quite accurate, but it is suitable only for small areas as well as it is very labor-intensive and requires access to the area of interest so it takes a lot of time, etc.

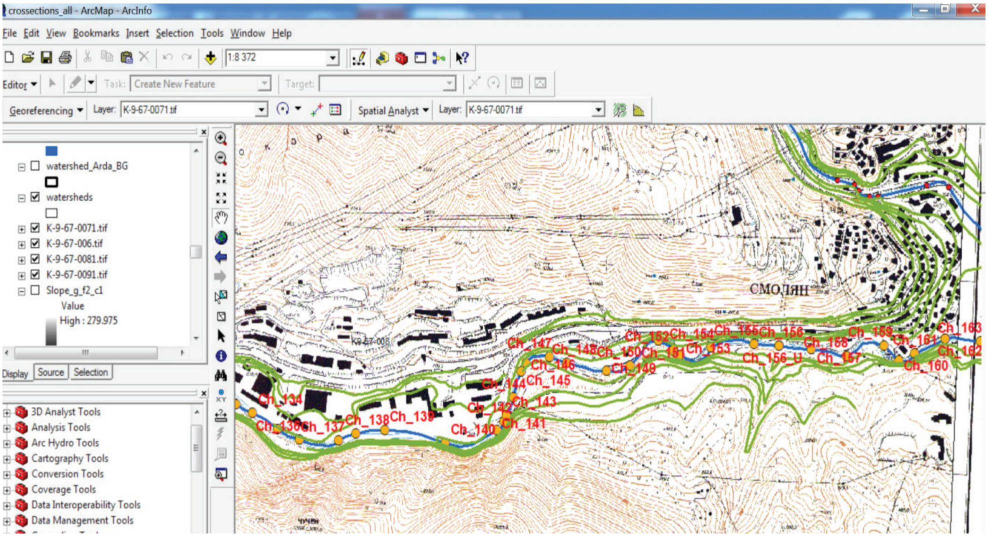

Fig.1. Digitizing a topographic map

Aerial photogrammetry with Drone – this is another method to create a DEM and DSM. Performed shooting with drone (unmanned aerial vehicle) to nadir or near nadir images (Figure 2). Filming takes place on a pre-prepared flight plan, tailored to the scope of the site, the required accuracy and the possibilities of the drone. The capture is processed with specialized software for photogrammetric reconstruction, from which a three-dimensional (3D) model is obtained. The advantage of this method is that the process is fast, not very expensive and the accuracy is sufficient. Of course, there are disadvantages, appropriate meteorological conditions are required for the flight, the flight session is limited in time by the durability of the battery, etc.

LiDAR - Relatively new technique in creation of DEM and DSM is application of the LiDAR. (LIght Detection And Ranging). It is a pulsed laser beam (cloud) transmitted by a transmitter (located on a flying platform - airplane, helicopter, balloon, satellite and etc.), reflected from an object (land surface) and registered by a receiver located on the same platform (Figure 3). The distance between the LiDAR device (combining the transmitter and the receiver) and the reflecting surface is calculated based on the speed of light and the time between the beam sending and the registration of the reflected signal (Milev, 2010). Parallel with this, a space location system is used. Actually coordinates of the points of the scanning surface are calculated together with other information like the intensity of the laser beam. Scanning systems are used to create a two-dimensional or three-dimensional presentation of the area. The airplane or the helicopter is equipped on board with a scanning camera, a scanner (most often a photogrammetric camera), a differential GPS / GNSS. They determine the position of the helicopter in the space, relative to the geodetic coordinate system (World WGS, state or local). LiDAR systems are used to measure high-precision airborne distances and a set of topographical data.

LiDAR is a revolutionary, fast-developing, efficient technology for aerial and space shooting. It allows data collection for large areas, land (farmland, forests, urbanized areas, industrial zones, etc.) and creation of Digital Elevation Model and Digital Surface Model. Obtained Digital Elevation Models are with high resolution and provide significant details. The accuracy in determining the position of the points is 2-4 cm. The resulting DEM has a vertical accuracy <12 cm and a horizontal accuracy <50 cm (Moslinger &Milev, 2005).

Fig.2. Drone

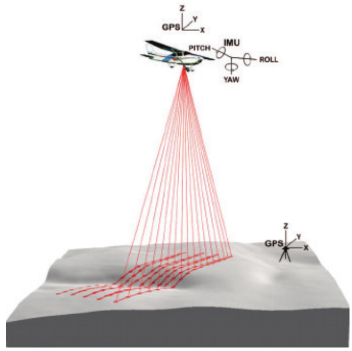

Fig.3. Air laser scanning

3. STUDY AREA

In this article we will explore the area of Bulgaria, Smolyan town, Ustovo neighborhood (Figure 4). In this region Byala River flows into the Cherna River.

The town of Smolyan is situated in the central part of the Rhodope Mountains, southern Bulgaria. The population of the city by 2015 is 30507 people. The average altitude of the city is about 1002 m. It occupies the greater part of the Cherna valley. On the two banks of the river in the direction west-east are located the three big neighborhoods - Smolyan, Raikovo and Ustovo.

In the Smolyan town almost every year there are floods. The topography of terrain of the city is mountainous, with steep slopes. Almost every intense rainfall in the city leads to floods. One of the places in the city, where floods are often recorded, is where Byala River flowing in the Chrena River. Most of the buildings in the town are adjacent to the riverbed and are under threat of flooding (Figure.5). A typical example is the three residential blocks which are clearly visible on the map.

Fig. 4. Study area – town Smolyan, Ustovo neighborhood

Fig.5. Flood in Ustovo neighborhood 2018

4. CREATION OF DEM AND DSM WITH TWO DIFERENT METHODS AND GENERATION OF COMPUTATIONAL MESH FOR HYDRAULIC MODELING WITH HEC-RAS 5.0.3

We will look at two methods for creating DEM and DSM and we will analyse the generated computational mesh for them with the hydraulic model HEC-RAS.

The first method is based on digitizing maps. The maps are scanned, then georeferenced and digitized with appropriate software for this purpose. The accuracy of DEM depends on the interval between the contours. As the contour density is greater, the more accurate DEM is created. In this case, a DEM has been created based on digitized information from topographical maps at a scale of 1:5000 - topographical points, contours, and river network. Created grid is with a cell size of 5/5 meters (Figure 6). ESRI software ArcInfo Workstation and TOPOGRIDTOOL are used.

TOPOGRID is an interpolation method specifically designed to create a hydrologically correct DEM of relatively small but well-selected information on altitudes and river network. It is based on an ANUDEM program created by Michael Hutchinson (1988, 1989) (Vassilopoulou, & Hurni, 2001). The interpolation process: uses the type of available input data and the known altitude characteristics; uses discretized thin plane spline technique; considers water as the main factor of erosion and forming the major forms of the earth's surface; provides drainage of water; uses contours; performs multi-resolution interpolation.

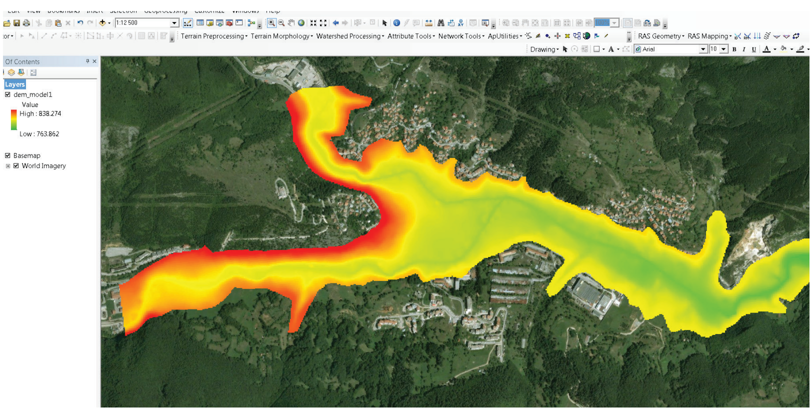

Fig.6. Created grid with a cell size of 5/5 meters

For hydraulic modeling the HEC-RAS software product is selected. The created DEM is inserted into the GIS application to the model – RAS Mapper. Flow area, upstream and downstream boundary conditions are set (Figure 7). The spacing between the computational grid-cell centers is defined 5 m x 5 m everywhere and regular computational mesh is created. Then breaklines are added around which the cells will be in an irregular shape.

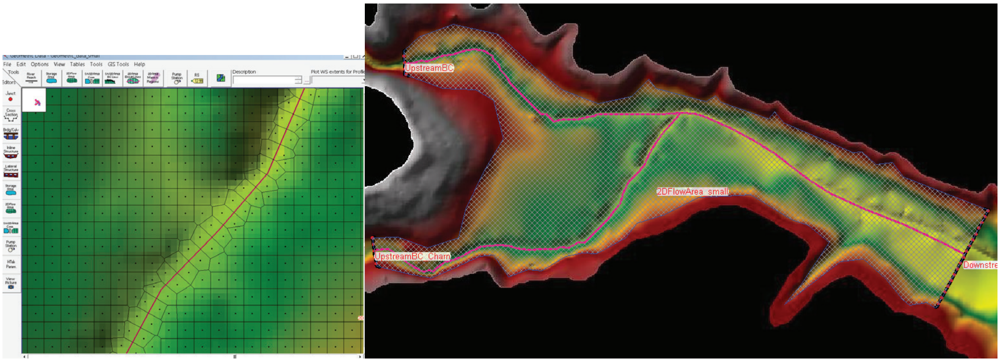

Fig.7. Computational mesh with DEM cell's size of 5/5 meters

The second method is based on photogrammetry with Drone.

The method of photogrammetry with drone is chosen, as more appropriate for this research than the method with LiDAR. The decision is taken after a brief analysis of the two methods. The method of photogrammetry with a drone is suitable for small areas, settlements, the accuracy is good enough and the price of the service is significantly lower. The method with LiDAR is more suitable for large areas (agricultural land, industrial zones, etc.), and its price is still very high.

Processes of survey with Drone: A flight plan is being prepared. A few reference points within the scope of the flight plan are surveyed. Survey is performed with at least 60% longitudinal overlap and 30% crosswise overlap of photos. Through several software products, the photos are processed and snapped to the reference points. Mathematical algorithm is applied to minimize errors and identify all unknowns, creating a cloud of points. The cloud of points is automatically, semi-automatically or manually edited.

As a result of these processes, DEM, DSM and orthophoto image can be obtained. Figure 8 shows the result of the photogrammetry method with a drone in the form of DSM.

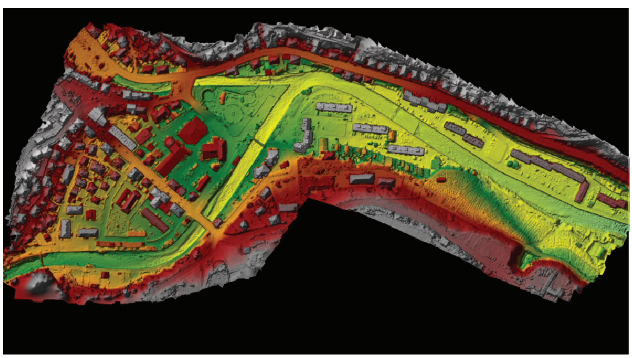

Fig.8. DSM with an accuracy of 10 cm

For this case, we use DSM to create a computational mesh of the hydraulic model. The accuracy of the resulting DSM is 10 cm. The method of creating the computational mesh is the same as for DEM with 5m accuracy, but here it will use a distance of 5m cell centers for regular computational mesh and of 1 to 10 m around the breaklines (Figure 9).

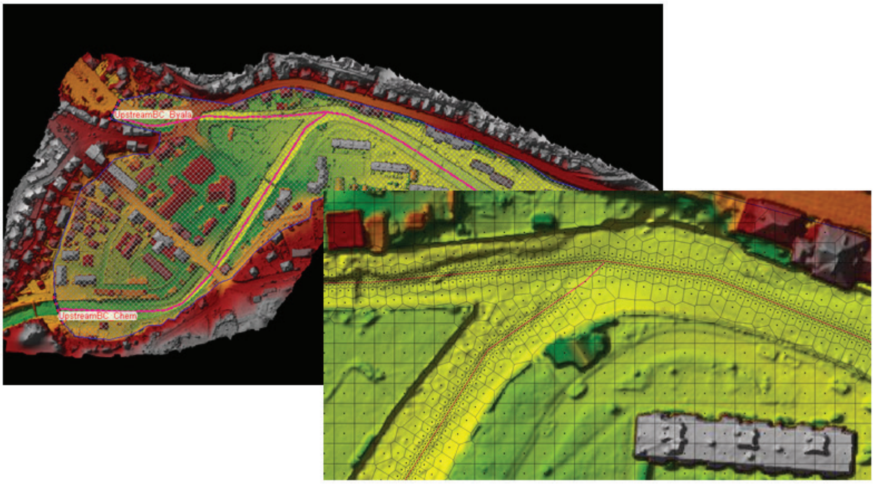

Fig. 9. Computational mesh with DSM cell's size of 0,1 / 0,1 meters

5. CONCLUSION

The 2D flood modeling and creating of flood hazard maps requires information on terrain, which quality depends on the acquisition techniques and the terrain of the study area. Complex and densely populated urban areas require more detailed terrain elevation data compared to rural area.

The study clearly shows the importance of a more detailed and accurate DEM or DSM for the creation of computational networks in the hydraulic modeling of settlements with close constructions. The presence of all detailed contour lines (dikes, roads, buildings, bridges, etc.) that are obtained by photogrammetry method with drone allows them to be mapped as breaklines in the RAS Mapper and to obtain cells from the computational network in a different form to better describe the flow way.

In such surveys for uninhabited areas, like farmland where the relief is flatter, the map digitization method is quite appropriate. When there are channels, dikes or other linear objects, they are well described by the horizontal and can easily be introduced as breaklines. The integration of all the available elevation datasets should be made very carefully. This will provide an accurate and detailed Digital Elevation Model to create a quality computational mesh as the foundation of the hydraulic model. Moreover, this is one of the cheapest approaches in creating terrain model without very precise and expensive elevation data acquisition techniques, for instance, LiDAR, Radar Interferometry and Photogrammetry.

Finally as the study is aimed to the creation of DEM and / or DSM suitable for mapping the threat of flooding in settlements, for the hydraulic model of the Cherna River and the Byala River in the region of Smolyan data from a photogrammetric method with a drone will be used.

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