Estimating Flash Flood Discharge in a Catchment Area with the Use of Hydraulic Model and Terrestrial Laser Scanner

D.D. Alexakis, D.G. Hadjimitsis, and A. Agapiou

Abstract A flood can be determined as a mass of water that produces runoff on land that is not normally covered by water. This paper aims to define the potential utility of terrestrial laser scanning data and hydraulics for improving flood risk assessment models in Yialias catchment area in Cyprus. Recently, terrestrial scanners have been used to capture 3D point cloud data of high accuracy for inundation models. Thus, different methods are used to process the scanning data in order to extract hydraulically relevant information. For this reason a variety of Digital Elevation Models (DEMs) of different spatial resolution was derived. The combined use of a two dimensional (2D) numerical hydraulic model and a terrestrial laser scanner can give the opportunity of estimation of peak discharge of a recent flash flood. Hence, the approach used in this study demonstrated the potential of hydraulics and laser scanner for flood risk assessment in catchments with infrastructure and vulnerable goods.

1 Introduction

The last years the urgent demand for flooding predictions caused by events of different return periods has increased markedly (Hall et al. 2005; Dawson et al. 2005). The practically instantaneous occurrence of flash floods together with their capacity of transport renders flash floods which is one of the most significant weather-related hazards in many parts of the world, causing considerable economic and human losses every year (Gaume et al. 2009).

Recently the growing understanding of the interaction between surface morphology and geomorphological processes as well as the awareness of the wide spatial and temporal processes take place, have increased the need for accurate and continuous three dimensional descriptions of topography (Lane et al. 1998). Thus

D.D. Alexakis (✉) • D.G. Hadjimitsis • A. Agapiou
Cyprus University of Technology, Limassol 3603, Cyprus
e-mail: dimitrios.alexakis@cut.ac.cy

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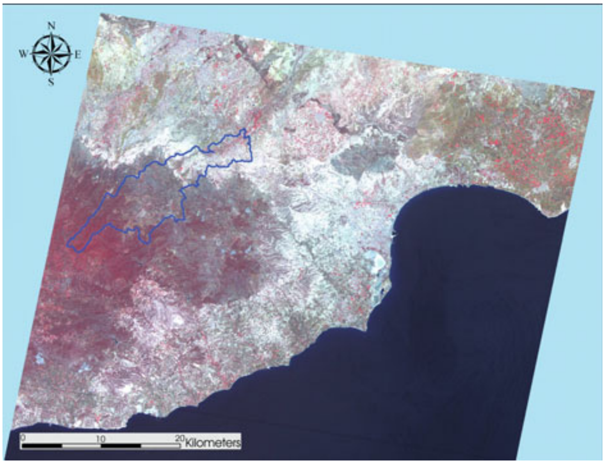

Fig. 1 Aster image (RGB – 321) of the study area. With blue outline the Yialias catchment area is indicated

a detailed description of fluvial topography is essential to accurately model the extent of the flooded areas. Currently the most accurate method for collecting elevation data for the production of Digital Elevation Model (DEM) is laser scanning (Cavalli et al. 2008). Terrestrial laser scanners (TLS) offer a high potential for the 3D mapping of smaller areas with high detail, a range accuracy of up to 1–2 mm and a scanning speed of up to 1M pts/s. The principle of TLS is simple, involving highly collimated laser-beam scans over a predefined solid angle in a regular scan pattern and the measurement of the time of flight of the laser signal.

This study strived to demonstrate in preliminary stage the potential of hydraulics and laser scanner for flood risk assessment in catchments with infrastructure and vulnerable goods. Specifically, after the extraction of major hydrologic parameters in GIS environment with the use of medium resolution DEM the research team proceeded to the construction of a high resolution DEM in the downstream of the basin in order to incorporate it in HEC-HMS software and implement a detailed hydraulic/hydrologic study of the area.

2 Study Area and Data

Located in the central part of the island of Cyprus the study area is about 110 km^2 in size with an average slope value of 7.19% (Fig. 1). Specifically the study area is situated between longitudes 33° 11′ 24, 28″ and 33° 26′ 31, 52″ and latitudes 34°54′36, 74″ and 35°2′ 52, 16″ (WGS' 84, 36°N). The island of Cyprus is located in the northeastern most corner of the Mediterranean Sea and, therefore, has a typical eastern

Fig. 2 Map of the catchment area indicating the subbasins, the rain and the stream gauges (*left*). Bridge in the downstream area of the basin where extreme inundation phenomena have taken place during 1992, 2003 and 2009 (*right*)

Mediterranean climate: the combined temperature–rainfall regime is characterized by cool-to-mild wet winters and warm-to-hot dry summers (Michaelides et al. 2009).

For the purposes of the study a Digital Elevation Model (DEM) of 25 m pixel size provided by the Department of Land and Surveys of Cyprus was used. The specific DEM was created with the use of ortho-rectified stereo-pairs of aerial photos covering the study area. At a next step the DEM was incorporated in GIS environment in order to delineate the basin's drainage network and extract the subbasins (13 subbasins) (Fig. 2). Moreover, flow accumulation, slope and elevation maps were produced in order to support the hydrological study of the area.

The elevation of the basin ranges from 194 to 1,408 m. In the upstream area the topography is steep though in the downstream is smooth. The geology of the basin is mainly volcanic with pillow lavas and basal group formations. Moreover, there are extended areas with marl/chalk formations of low hydropermeability and alluvium/colluviums deposits in the downstream. During the last 20 years three extreme floods have occurred in the basin, especially in the downstream area. According to historical data the most extreme events took place on 2 December 1992, February 2003 and 27 October 2009. All these extreme floods caused significant damage to properties and constructions.

3 DEM Creation

The Leica ScanStation C10 laser scanner was used for documentation of Yialias catchment area at the area where its bank gets really narrow due to anthropogenic interventions. This laser scanner may scan up to 50,000 points per second, while the accuracy – as provided by the developer – is ±6 mm/50 m distance. The field of view of the Scan Station is 360° × 270°. Laser Scanner was used in conjunction

Fig. 3 Rover GPS equipment (*left*). Use of the Leica ScanStation C10 laser scanner in Yialias catchment area (*right*)

with differential GPS instrument. The Leica GNSS Viva was used for this purpose. A reference base was set up at a triangulation pillar of the local reference system of Cyprus (WGS 84, Local Transverse Mercator). A rover GPS equipment was used in order to measure characteristics points of the Yialas basin (Fig. 3). The accuracy of the measurements was less than 2 cm (3D measurements).

The laser scanner allows acquiring the reflected beam intensity and RGB colours. Tripods and the HDS scan targets are the main accessories of the instrument. The post-processing of the laser scanning includes some standard procedure. To accurately model the flow of water over the floodplain the DEM derived from the TLS point data must preserve all the important geometric details affecting the flow. At first, after the data are downloaded to the computer the registration of the point’s clouds was applied in the Cyclone software. The registration was performed automatically using the special targets. Afterwards, an ICP (Iterative Closest Point) algorithm was applied in order to achieve a highest accuracy of registration of the point clouds in the same software. The relative accuracy of scans was up to 2 cm (RMS) between the point clouds. After the ICP algorithm was applied the accuracy was found to be less than 1.5 cm (Fig. 4). However, the accuracy of the registration can only be evaluated by using Check Points (CP) not used for the estimation for the registration parameters. The next step of the post-processing is the automatic and manual cleaning of the data. This is a necessary step in order to minimize the noise which appears in the point clouds and to define a perimeter of the area of interest. In order to model the water flow accurately it is important to include the channel bathymetry in the model as well as the objects that affect the direction and velocity of water flow in the over bank situation such as buildings, bridges etc. (Mandlburger et al. 2009). After the cleaning of the data the mesh procedure can be performed using all the points’ clouds. A 3D mesh was created in the 3D Reshaper software.

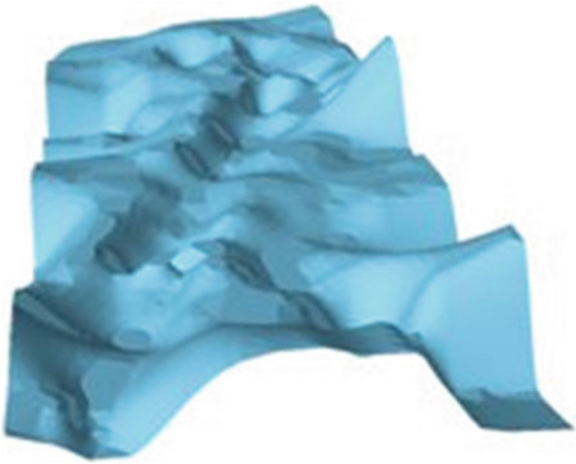

Fig. 4 Preliminary result of the DEM output in the downstream with the use of only the elevation data derived from the GPS survey

4 Run-off Model Description

The runoff process is modeled using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). The specific software was developed by the US Army Corps of Engineers and is designed to simulate the precipitation – runoff processes of dendritic watershed systems. Moreover it gives the chance to the end user to choose between numerous infiltration losses parameterizations (Knebla et al. 2005).

The final hydraulic model requires as input the hydrographs derived from HMS. The parameters of the model are representative cross-sections including left and right bank locations roughness coefficients (Manning's coefficient) and finally contraction and expansion coefficients. The roughness coefficients are crucial for the implementation of the model (they represent a surface's resistance to flow and are integral parameters for the calculation of water depth) and are calculated by combining land use data with tables of Manning's *n* values.

As it was mentioned the rainfall-runoff models simulate the runoff response of an area to a given amount and distribution of precipitation over a certain period of time. The output of the model is the discharge hydrograph at each sub-basin outlet which defines each sub-basin's unique runoff response due to differences in watershed properties such as geomorphology, geology and anthropogenic effects. The research team will incorporate the spatial data (DEM from laser scanner) and precipitation data from the meteorological stations in and outside of the basin in order to simulate the hydrologic/hydraulic response of Yialias river during extreme weather phenomena.

5 Conclusions

This review of the application of laser scanning in fluvial studies has shown that laser scanner data have great potential to improve the effectiveness of topographical data acquisition and the accuracy and resolution of DEMs. The integration of hydraulic geometry methods and 3D scanner with the use of bed roughness and high quality topographic data have proved to be a great alternative for searching the watershed regime in flood prone areas. The detailed DEM constructed by 3D laser scanner provides the model with reliable data related to the geometry of the cross-sections.

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