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Hydrological analysis and hydraulic simulation for Sperchios River Basin

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Abstract This research work deals with a flood risk assessment methodology for the ungauged Sperchios River basin, an area of 1003 km^2 located in Central Greece. This region is frequently exposed to floods, thus a floodplain evaluation is very important in order to take measures against the effects of floods. Initially, a hydrological analysis was conducted through the Hydrologic Modeling System (HEC-HMS) using the estimation of the runoff, based on the Natural Resources Conservation Service (NRCS) method and the appropriate curve numbers (CN) for the study area. The output of the hydrological analysis was a flood hydrograph, which was then used for hydraulic simulation through the River Analysis System (HEC-RAS) (2D), having the ability to produce the water profiles, velocity and inundation maps of the floodplain. The results of this work indicated that surface runoff is equal to 66% of the total rainfall and the flood hydrograph peaks at 1969 m^3/s, under normal soil moisture conditions. An increase of 22% in the surface runoff, leads to a peak of 2756 m^3/s (40% increase), under wet conditions. The adopted methodology contributes to the development of robust flood forecasting and early warning systems.

Keywords: surface runoff, floodplain evaluation, HEC-HMS, HEC-RAS, Sperchios

1. Introduction

Flood is a frequent natural disaster which can cause adversity to the country and people. The continuous increase of flash flood phenomena and their devastating consequences worldwide require the constant improvement of flood risk management and modeling (Kastridis and Stathis, 2020). There are several qualitative or quantitative approaches (e.g., Anselmo et al., 1996; He et al., 2004; Du et al., 2006; Huang and Huang, 2007; Meyer et al., 2009) that can evaluate flood risk and therefore the flood hazard maps can be drawn up. The quantitative approaches concern advanced hydrologic and hydraulic models. The hydrologic model estimates flood peaks and volumes focusing mostly on the line-type distribution of floods (Shi, 2003). The hydraulic model examines the propagation in time and space of the flood wave into the river banks and over the floodplains. Sun et al. (2018) presented a nonstationarity-based evaluation of flood frequency and flood risk in the Huai River basin, China. Mahmood et al. (2019) implemented an integrated hydro-probabilistic approach by clubbing the results of HEC-RAS and Hydrologic Engineering Centre's Geographic River Analysis System (HEC-Geo-RAS) in Geographic Information System (GIS) environment for spatial appraisal of flood risk assessment and evaluation in Panjkora River Basin, Pakistan.

The objective of this research work was to assess the flood risk in Sperchios River Basin. A hydrological analysis was conducted for a subbasin of study area with the use of HEC-HMS software, calculating the flood hydrographs under two soil moisture conditions. Subsequently, a hydraulic simulation was performed downstream of the subbasin outlet in order to produce two flood hazard maps with the maximum water depth along the simulated section of mainstream through HEC-RAS software. This methodology results in the floodplain evaluation, which can contribute to flood forecasting and flood risk management.

2. Study area and data used

The study area consists of Sperchios River basin that covers an area of 2318 km^2, and a subbasin (1003 km^2) of the River defined by the outlet point near of Lianokladi village as shown in Figure 1. The area used for the hydraulic simulation is thought to be a point of interest as it contains a road bridge that stands at 9 m above the riverbed, and two villages, making it important to simulate the water depth in a flood event as it poses a threat in human life aside from the material damages that may occur. Sperchios River has a length of 82 km and is located in the water district of Eastern Central Greece. Sperchios Valley has complex vegetation and land use, and powered by torrential streams that spring from the mountain Vardousia (2.286 m), Mount Othrys (1.170 m) and Mount Kallidromo (2.116 m) (Paparrizos et al., 2017). The runoff of Sperchios River ends up in Maliakos Gulf, the coastline of which is the eastern limit of Sperchios basin.

Regarding the required data for the analysis, the Digital Elevation Model was obtained by the National Cadastre & Mapping Agency of Greece. The dataset pixel size is 5 m x 5 m, its geometric accuracy RMSE is $z \leq 2.00$ m and the absolute accuracy is about 3.92 m for a 95% confidence level. Additionally, the analysis was based on Corine Land

Cover (2018), geological maps, other DEM-derived geomorphological and hydrological attributes, such as the slope and streams definition, data for the Intensity-Duration-Frequency (IDF) curves from the Ministry of Environment and Energy as well as Manning roughness coefficient estimated according to the global literature (e.g., Barnes, 1967).

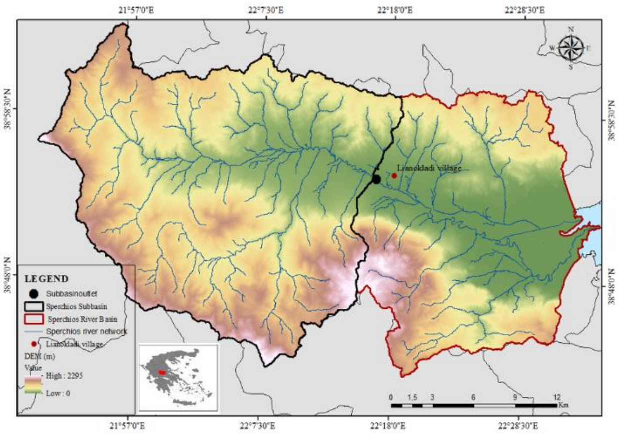

Figure 1. Sperchios River Basin

3. Methodology

The hydrological analysis was performed for the subbasin based on the NRCS method utilizing the HEC-HMS software, which is widely used developed by the U.S. Army Corps of Engineers, that performs the rainfall-runoff simulations with the use of preselected sub-models [USACE, 2018]. The application of NRCS method requires as input data into HEC-HMS the design hyetograph, the rainfall losses and also the lag time. The calculation of design hyetograph was conducted through the parameters of Intensity-Duration-Frequency (IDF) curve for the Pyra hydrometeorological station using a return period of 100 years and precipitation duration of 24 hours, from which the rainfall intensity was calculated. The time distribution of the design hyetograph was performed applying the alternating block method. The cumulative rainfall distribution can be produced after calculating the product of the rainfall intensity and the duration for each rainfall duration. The rainfall intensity is calculated as the difference between the successive cumulative rainfall depths. Finally, the rainfall peak is located at the center and the next largest rainfall intensity is located alternately to the right and left of the rainfall peak in turn. (Na and Yoo, 2018). Regarding the rainfall losses depend on factors such as soil type, vegetation type and density, land use, percent of impervious area, and antecedent runoff conditions, which concern a measure of how dry or wet a watershed is at the beginning of a storm (FEMA, 2018). In order to take all these parameters into consideration, the NRCS has categorized soils based on their runoff potential into four groups and then the Ministry of Environment and Energy gave values to CORINE codes based on what type of soil they are, known as CN. Then the CN value of the subbasin was given by the eq. (1). Moreover, in this work the wet soil conditions are also examined using the eq. (2).

$$CN_{II} = \sum_{i=1}^{n}(\frac{A_i}{A} \cdot CN_i) \qquad \text{(eq.1)}$$

where CNII is the subbasin's curve number under normal circumstances, Ai (i=1, …, n) is the area of the subsurface i with a curve number of CNi, and A is the subbasin's area.

$$CN_{III} = \frac{2.3 \cdot CN_{II}}{1+0.013 \cdot CN_{II}} \qquad \text{(eq.2)}$$

The lag time of subbasin is given according to Mockus V. (1957) by the eq. (3).

$$t_L = 0.6 \cdot t_C \qquad \text{(eq.3)}$$

where t_C is the time of concentration (h) of subbasin based on Giandotti M. (1934)

The result of hydrological analysis is two flood hydrographs, which were imported into HEC-RAS 2D model along with the DEM and the manning roughness coefficient dataset, where the hydraulic flood simulation was performed 3 km along the simulated section of mainstream downstream of the subbasin outlet. HEC-RAS is one of the recognized spatial hydrological models used for channel flow analysis and floodplain delineation developed by the US Army (Solaimani 2011). The output of simulation is the floodplain evaluation producing the flood hazard maps for the maximum water depth under two different soil conditions.

4. Results

According to the hydrological analysis described above, the CN values of the subbasin were estimated at 73 and 86 under normal and wet soil conditions respectively and the calculation of lag time was 5.88. These parameters along with design hyetograph were imported into HEC-HMS model, which produced two flood hydrographs under normal and wet soil conditions as shown in Figure 2 a, b respectively. As it was expected, the higher the soil moisture is, prior to the event, the bigger the peak flow is and the lesser the rainfall losses are. More specifically, peak flow is estimated at 1969 m^3/s under normal soil moisture conditions, while under wet conditions, the peak flow is estimated at 2756 m^3/s. Surface runoff under normal soil moisture conditions is the equivalent to 66% of the total rainfall, while under wet conditions it equals to 88% of the total rainfall. As it was expected, the higher the soil moisture is, prior to the event, the bigger the peak flow is and the lesser the rainfall losses are. More specifically, peak flow is estimated at 1969 m^3/s under normal soil moisture conditions, while under wet conditions, the peak flow is estimated at 2756 m^3/s. Surface runoff under normal soil moisture conditions is the equivalent to 66% of the total rainfall, while under wet conditions it equals to 88% of the total rainfall. Regarding the hydraulic simulation, the flood hazard maps for different soil conditions is produced indicating the water profiles, velocity and inundation maps of the floodplain. Under normal soil moisture conditions, the flooding water's free surface at the bridge of Lianokladi is 9.3 m above the riverbed, while an increase of 22% to the surface runoff, under wet conditions, leads to a water depth of 10.5 m (Figure 3a, b).

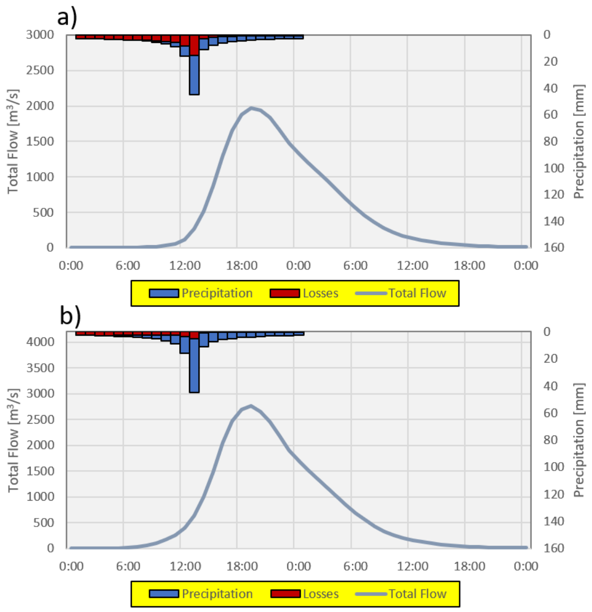

Figure 2. Flow hydrograph at the outlet of the subbasin a) for normal soil conditions CNII, b) for wet soil conditions CNIII

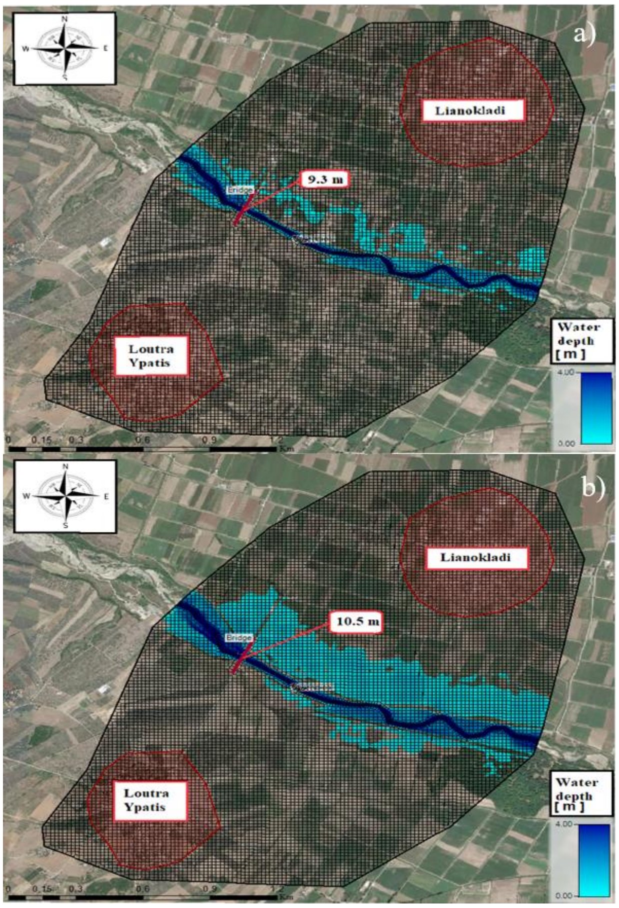

Figure 3. Flood hazard map of Sperchios river basin (maximum depth and velocity) a) for normal soil conditions CNII, b) for wet soil conditions CNIII

5. Conclusions

This paper presents a methodology under two different initial soil conditions for flood risk assessment in ungauged Sperchios River Basin. It is obvious from the hydrological analysis that surface runoff under wet conditions was increased 22 %, which leads to 40% increase in peak flow of flood hydrograph. Additionally, an increase of 22% to the surface runoff, under wet conditions, resulted in 12.9 % increase of the water depth at the Lianokladi bridge. The bridge stands at 9 m above the riverbed, hence taking into consideration the results of the hydraulic simulation under different conditions for a flood event of 100 years return period, local authorities preventing the passage from the bridge under such events is thought to be justified.

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