FLOOD HAZARD AND RISK MANAGEMENT UTILIZING HYDRAULIC MODELING AND GIS TECHNOLOGIES IN URBAN ENVIRONMENT

TZIMA K. and PAPADOPOULOU M.P.

Laboratory of Physical Geography and Environmental Impacts, School of Rural and Surveying Engineering, National Technical University of Athens, 9 Iroon Polytechniou, University Campus, 15780 Zografou, GREECE
E-mail: tzimakleopatra@gmail.com and mpapadop@mail.ntua.gr

ABSTRACT

Floods are natural phenomena that occur when the capacity of a drainage system (natural or artificial) cannot channel the volume of water generated by a rainfall event. Floods are considered the most common and destructive type of natural disasters worldwide. Exposure of human life at risk, material damages to infrastructure, destruction of crops, soil erosion and pollution of water discharges are some of the most important impacts. The current study focuses on the assessment and management of flood risk in a sub-urban region by utilizing hydraulic modeling approaches. Geographic Information Systems (GIS) were used to process, analyze and visualize hydraulic and spatial data. The aim of this study was to estimate the flood hazard and risk for a specific flood event in order to estimate the consequences in the natural and socio-economic environment in the greater urban region and propose the appropriate mitigation measures.

For these purposes, the watershed of "Katounistra" stream located in the southern area of Loutraki City, Greece was simulated using HEC-RAS algorithm. The simulation results determined flood depths, flow rates and flood extent for three different hazard scenarios (high, medium and low) based on the return period. These elements then were analyzed, mapped and visualized through the geographical information system ArcGIS in order to obtain the flood hazard of Katounistra catchment. Subsequently, model hydraulic outputs were correlated by means of appropriate indicators and functions with data relating to the socio-economic environment of the region. Thus, two scenarios, a social and an economic, were developed and a quantitative assessment and analysis of flood risk performed both for human lives and building infrastructures.

Keywords: Flood Risk, Climate Change Impacts, Geographic Information Systems (GIS), Hydraulic Simulation Models

1. Introduction

Floods are considered the most common and destructive type of natural disasters worldwide (Downton and Pielke, 2001). Exposure of human life at risk, material damages to infrastructure, destruction of crops, soil erosion and contamination / pollution of water discharges are some of the most important impacts due to climate change. Experts claim that a warmer world will trigger the occurrence of extreme droughts, forest fires, floods and storms, setting humans, ecosystems, crops and coastal towns at a greater risk. Approximately 20% of the world population that live in river basins are likely to be affected by increased flood risk which may arise from a possible climate change (Kleinen and Petschel-Held, 2007). According to the 4th IPCC report the number of regions affected by floods due to heavy rains increases as a possible consequence of climate change. It is stated that one of the most assured predictions of all of the climate models is the intensity increase of rainfall that will occur in warmer climate conditions affecting mainly the risk of sudden and urban flooding (Kundzewicz *et al.*, 2005). The current study has as main objective the development of an integrated methodological framework for the estimation, analysis and mapping of flood hazard and flood risk afforded by rainfall events in an area. Based on European Commission guidelines flood hazard maps present the extent and expected water depths/levels of a flooded area based on three possible scenarios (low, medium and high). Population, economic activities and environment at potential flood risk will be presented in flood risk maps. The area under consideration to implement the proposed methodology was the watershed of "Katounistra" stream which is located in southern of Loutraki City. The basin covers an area of 3.13km^2 with an elongated shape and maximum altitude of 260m (Figure 1). The area is characterized by mild terrain downstream, with slopes up to 5%. On the other hand, the upstream mountainous part of the basin has strong topography with slopes up to 40%. The main stream is 6.40km long and the riverbed is gradually limited downstream until it disappears just before reaches the sea causing flooding events, with serious consequences in sub-urban areas.

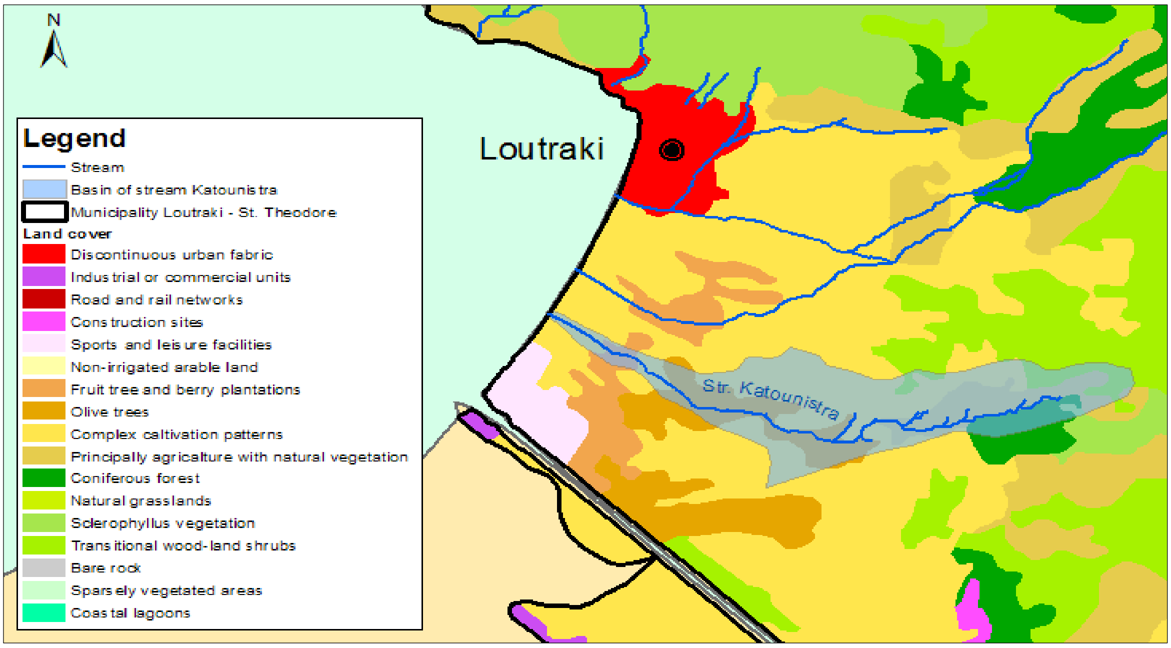


Figure 1: Watershed of the "Katounistra" stream

2. Methodology

The methodology that was followed in the current study in order to define the flood hazard and flood risk levels in the area of interest is summarized in Figure 2.

2.1. Flood Hazard Assessement

The need to adapt to extreme weather events requires appropriate preventive and protactive measures in order to minimize the consequences of a flood event. An important step to this direction is the assessment and analysis of flood hazard in the area of interst due to a rainfall event. For this purpose, in the current study the hydraulic models HEC-RAS and HEC-geoRAS developed by United States Army Corps of Engineers were chosen to simulate the hydraulic behavior of Katoynistra stream. Having determined all the necessary elements, hydraulic simulation was perfomed for three scenarios with different return periods, low (T=20), medium (T=50) and high (T=100) probability. The results were imported in HEC-geoRAS of ArcGIS in order to obtain spatial reference and develop the corresponding flood hazard maps.

2.2. Flood Risk Analysis

Flood risk is defined as the combination of the probability to occur flooding and its potential consequences in environment such as human health, building infrastructure, natural environment and cultural heritage (Meadowcroft *et al*., 2002). In this study the flood risk was quantified through spatial analysis in GIS (ArcGIS) and mapped in the area of interest for a rainfall event that occur once in 50 years (T=50).

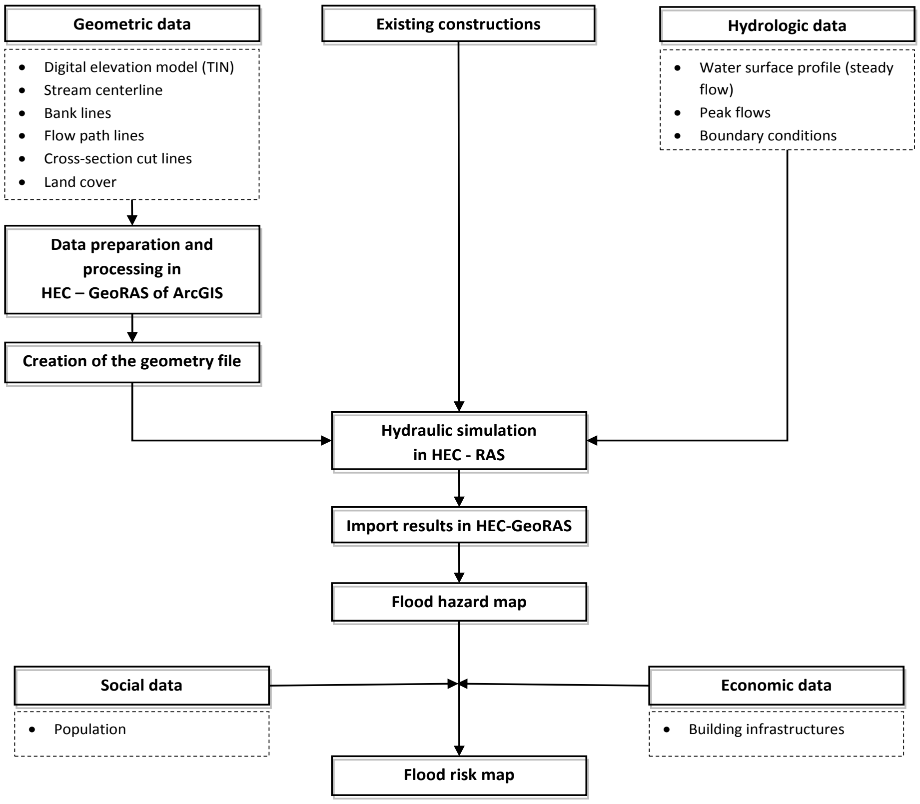


Figure 2: Proposed flood risk assessement methodology

Flood risk analysis was performed based on: a) the social and b) the economic ones. In the social scenario, the aim was to find and quantify the negative consequences caused by a flood event on the population. The estimation of flood risk to people was based on HR (Hazard Rating) index which is defined as (Wallingford *et al*., 2006).

$$HR=d*(v+0.5)+DF \quad (1)$$

Where HR is the flood hazard rating, D is the water depth (m), v is the flow rate (m/s) and DF is the debris factor.

In the economic scenario, the aim was to find and quantify the negative consequences on the building infrastructure in the greater region that may be affected by a flood event. Specifically, the percent of damage in buildings and the corresponding cost in monetary units was estimated. For this purpose, a function that correlates water depth and resulting damage (depth – damage function) was used (Stuart and Skaggs, 1992). For every $1m^2$ of building that may be affected, a corresponding damage percent based on the function was calculated. Then, these percentages were expressed in monetary units (€), considering the reconstruction cost (100% damage) of a typical residence in the area. Summing up the amounts for the total affected area the total amount of damage (in €) for each building was revealed.

3. Results

Hydraulic simulation of Katounistra stream was performed in HEC-RAS considering its physical characteristics and the existing infrastructure construction along the stream. In Figure 3 flood hazard map of downstream part is shown representing water depths and flooded areas for the high probability flood event. According to it, the flood affects the downstream part of the basin with water depths that reach up to 0.9m. In Figure 4 flooded areas for three different rainfall events (T=20, T=50 and T=100 years) were drawn showing that the maximum flooded area is estimated approximately equal to 83.656 acres corresponding to T=100 years flood event.

Figure 3: Flood hazard (T=50 years) in a sub region of the study area

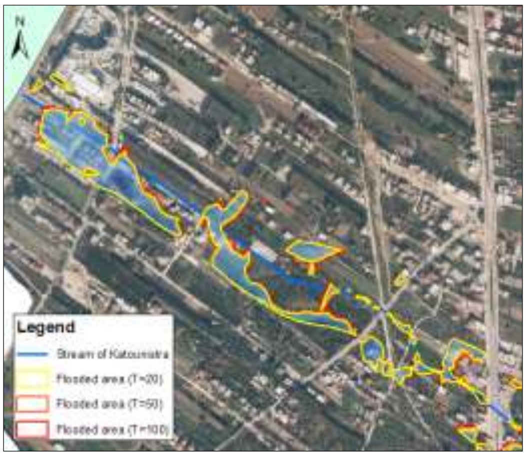


Figure 4: Flooded area for the three different return periods

Table 1: People at risk in the different flood risk zones

HR	Hazard Rate	Risk Level	Number of Inhabitants
<0.75	Low	Caution	15
0.75 – 1.25	Moderate	Dangerous for some (e.g. children)	2
1.25 – 2.5	Significant	Dangerous for most	14
>2.5	Extreme	Dangerous for all	1

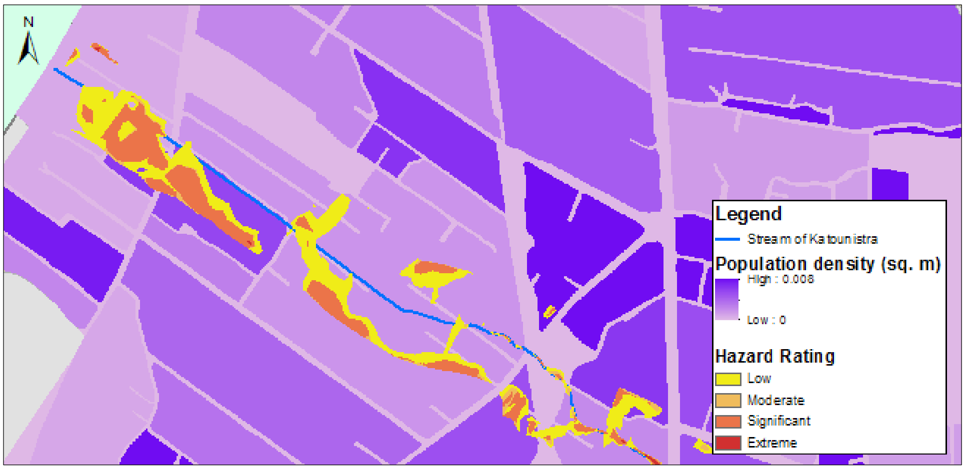
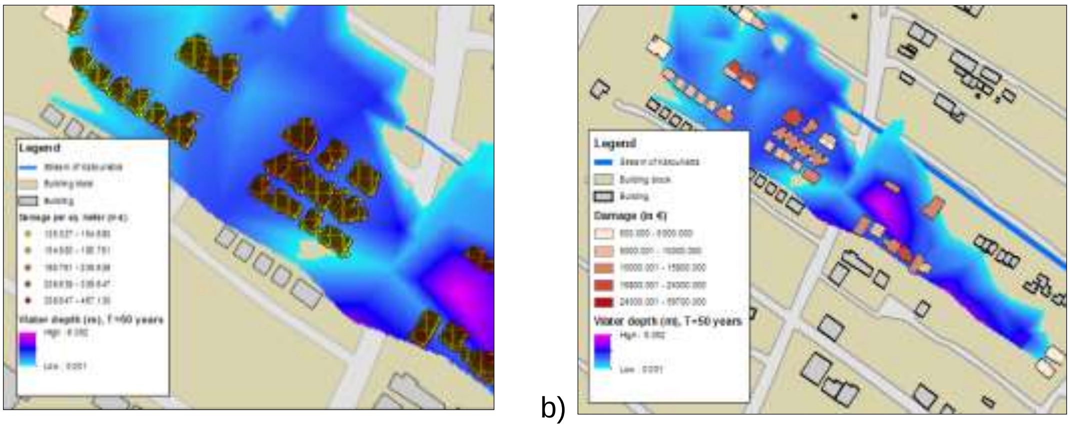


Figure 5: Flood risk of an event in part of the area of interest (T=50 years)

Concerning flood risk analysis, the hazard levels based on HR index and hydraulic modeling results were shown in Figure 5 for the social scenario. HR values vary spatially and corresponding risk levels to specific risk levels were assigned (Table 1). Finally, the number of inhabitants at risk was also calculated for each risk zone using current population data. From the economic scenario perspective, the total amounts of damage (in €) for each building that was affected by selected flood event (T=50) is shown in Figure 6. The analysis showed that the affected buildings were 81 in total and the overall damage cost reached up to 850.000€.



a) b)

Figure 6: Damage (in €) a) per square meter and b) in total for each building that was affected by the flooding event (T=50 years)

4. Conclusions

Flood hazard and risk were assessing utilizing hydraulic simulation and GIS methodologies. This approach is considered quite satisfactory that enables multifaceted overview of the problem, emphasizing on the specific spatial characteristics of the area under study. Following the proposed methodology, flood hazard could be quantified, mapped and spatial correlated with environmental variables. Thus, flood risk was converted from a theoretical concept to practical ready to be applied concept and constitutes an important indicator to estimate the vulnerability of a region.

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