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A national scale flood hazard mapping methodology: The case of Greece – Protection and adaptation policy approaches

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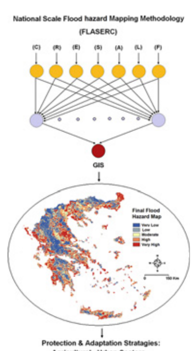
HIGHLIGHTS

- A new integrated national scale flood hazard mapping method based on GIS and ANN techniques
- This study provides, for the first time, a flood hazard map for entire Greece.
- The methodology was validated based on historical flood events.
- 24% of the total area of Greece is under very high flood hazard (50-year return period).
- An overview of flood protection and adaptation strategies for agricultural and urban sectors

GRAPHICAL ABSTRACT



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ABSTRACT

The present work introduces a national scale flood hazard assessment methodology, using multi-criteria analysis and artificial neural networks (ANNs) techniques in a GIS environment. The proposed methodology was applied in Greece, where flash floods are a relatively frequent phenomenon and it has become more intense over the last decades, causing significant damages in rural and urban sectors. In order the most prone flooding areas to be identified, seven factor-maps (that are directly related to flood generation) were combined in a GIS environment. These factor-maps are: a) the Flow accumulation (F), b) the Land use (L), c) the Altitude (A), b) the Slope (S), e) the soil Erodibility (E), f) the Rainfall intensity (R), and g) the available water Capacity (C). The name to the proposed method is "FLASERC". The flood hazard for each one of these factors is classified into five categories: Very low, low, moderate, high, and very high. The above factors are combined and processed using the appropriate ANN algorithm tool. For the ANN training process spatial distribution of historical flooded points in Greece within the five different flood hazard categories of the aforementioned seven factor-maps were combined. In this way, the overall flood hazard map for Greece was determined. The final results are verified using additional historical flood events that have occurred in Greece over the last 100 years. In addition, an overview of flood protection measures and adaptation policy approaches were proposed for agricultural and urban areas located at very high flood hazard areas.

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1. Introduction

Floods are considered to be among the most frequent and destructive types of natural disasters worldwide, with significant consequences including: a) human and animal life losses, b) destructions of infrastructures, communication networks, and agricultural/livestock buildings, c) loss of crops and soils, d) transport of sediment loads and pollutants (Downton and Pielke, 2001; Golian et al., 2010). Worldwide floods, especially during the last decades, record significant high rates both in absolute number of events, and in terms of financial losses. Specifically, it is estimated that floods cause about 40% of the damages caused by all natural disasters (Ologunorisa and Abawua, 2005; Munich Re, 2016).

The different types of flooding are: river floods, flash floods, coastal flooding, urban floods, and sewer flooding (Kourgialas and Karatzas, 2016). Flash flood in the Mediterranean areas is the most common type of flood which occurred due to the small size of the river basins (short-time flow concentration), the geomorphology (high slopes or/and low permeability geological formations), and the intense rainfalls (Diakakis et al., 2012). These characteristics make flash flood a common phenomenon not only to low-lying or adjacent to rivers areas, but also to mountainous plateaus. Flash floods are characterized as one of the most disastrous hazards in terms of mortality and infrastructures (Georgakakos, 2006). Recently, characteristic examples in Mediterranean countries where flash floods caused significant economical damages and/or human losses can be seen in Italy (Moramarco et al., 2005; Molinari, 2014), Greece (Kourgialas and Karatzas, 2014; Papagiannaki et al., 2015), France (Gaume et al., 2004; Delrieu et al., 2005), and Spain (Llasat et al., 2013).

Flash floods are strongly influenced by meteorological conditions and different land uses, thus flash flood events, in the upcoming decades, are going to be highly influenced due to climate and land use changes (Posthumus et al., 2008; Muis et al., 2015; Kourgialas et al., 2015). Roudier et al., 2016 investigate the hydrological impacts of a +2 °C global warming on extreme hydrological events (floods and droughts) in Europe. The results of this research show that flood magnitudes are expected to increase notably in areas south of 60°N, except in the areas of Poland, Bulgaria, and south of Spain, while north of 60°N floods will decrease, with the exception of some coastal areas in Norway and southern Sweden where floods probably will be increased. An integrated analysis of floods along with droughts shows that the impact of global warming will be more extreme in Spain, Portugal, Greece, France, and Albania. Specifically, flooding events will be expected to be more frequent in recent years especially in the Mediterranean region. Thus, all the necessary measures to avoid or minimize the consequences of the oncoming floods should be taken by the Mediterranean countries.

Many countries especially in Southeast Asia and Africa face a severe increase in flood risk (Di Baldassarre et al., 2010a; Winsemius et al., 2016). Flood risk maps are generated using multi-parametric approaches that combine physical (hazard) and socio-economic (vulnerability) factors. Nevertheless, existing global flood risk projections fail to accurate predict the dynamics of socio-economic development or/and climate change (Ward et al., 2015; Winsemius et al., 2016). The knowledge of flood hazard is also essential to adapt any strategy for minimizing the flood risk, which in turn can reduce the losses of human life and damages in urban and rural sectors (Pappenberger et al., 2013; Sampson et al., 2015). Flood hazards can be defined as threatening events, or the probability of occurrence of a potentially damaging phenomena within a given time period and area (Di Baldassarre et al., 2010b). However, in recent years, flood hazard maps are still lacking in many countries. This is mainly due the limited availability of adequate data for flood hazard studies such as hydrologic observations, historical flood events, and topographical surveys of channels/floodplains (Samela et al., 2017). All these data are rarer in ungauged river basins of many developing countries of Asia, Africa, or South America. Based on this, for producing large scale flood hazard maps, several researchers have addressed the prediction of flood hazard at ungauged sites by using regionalization methods, simplified hydrological routing schemes, methods based on geomorphology for generating relationships between flood and floodplain, and using high resolution satellite images for quantifying changes in surface water (Nardi et al., 2006; Dodov and Foufoula-Georgiou, 2006; Manfreda et al., 2011; Pekel et al., 2016; Samela et al., 2017).

Based on the Floods Directive 2007/60/EC, each member of the European Union should design flood hazard maps using different levels of hazard (probabilities of flooding). This classification would make the information of flood hazard more obvious to the local authorities and easily understandable to the public, providing at the same time valuable spatial information regarding the degree of flood hazard and the priorities regarding the planning of the flood protection measures (Yannopoulos et al., 2015). At the present time, reporting the progress of EU members on national scale flood mapping this information is missing from Bulgaria, Greece, Malta and Portugal. Thus, one of the aims of this study is to cover this knowledge gap providing an easy to be applied methodology for assessing flood hazard at national scale.

Hydrological/hydraulic models have been widely used in many flood mapping studies (Chatterjee et al., 2008; Ballesteros et al., 2011; Brocca et al., 2011; Kourgialas and Karatzas, 2014; Papaioannou et al., 2016). In many cases, these models are inadequate for ungauged or/and national scale areas, such as Greece, where the majority of the country's territory consists of small ungauged or poorly gauged river basins. Valuable tools to overcome these hydrological/hydraulic modeling limitations are the combination of artificial neural network (ANN) and GIS techniques. ANNs are commonly used data-driven methods that have proved capable of prediction of water resource variables with great accuracy. ANNs display mapping effectiveness to generalize reliable data in parallel with high speed. Based on these capabilities, ANNs are designed for pattern recognition and classification applications, which make them very suitable for flood forecasting (Toth et al., 2002; Rietjes and de Vos, 2008; Sulafa, 2014). Their drawbacks are related to their black box approach (no physical meaning of the concerning parameters), and extrapolation capacity (He et al., 2014). The ANN disadvantages can be overcome combining them with GIS techniques. GIS are particularly useful in flood hazard mapping as it can incorporate both the spatial and physical dimension of the floods (Yahaya et al., 2010; Wang et al., 2011; Chau et al., 2013; Kazakis et al., 2015). Up to now, flood mapping using ANNs and GIS have been applied in various small scale case studies (Islam and Sado, 2002; Masoud et al., 2012; Song et al., 2013).

The main objective of this work is to propose an integrated and easy to apply ANNs and GIS modeling approach, able to provide reliable large scale flood hazard maps in data scarce regions. This modeling approach combines different factor-maps which capture all the aspects of the hydrological cycle that contribute in flood generation. The proposed methodology shows an advance over existing methods, since: a) it integrates seven different factors, that are directly related to the flood development which are flow accumulation, land use, altitude, slope, soil erodibility, rainfall intensity, and available water capacity - into a unified GIS model that incorporates all information necessary to reduce the level of uncertainty of the flood hazard, b) it consolidates ANNs techniques in order to face an important problem in a GIS multi-criteria analysis. This problem is related to the determination of the weights of the involved factors, which in most cases are subject to the subjective estimation of the decision-maker, c) it is effectively adapted to complex geomorphological large scale environments, such as the country Greece, providing, for the first time, a flood hazard map for the entire country, d) it is validated for different historical flood events took place in Greece the last 100 years, and e) it provides an overview of flood protection measures and policy approaches for agricultural and urban areas located at very high flood hazard areas.