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Suitability estimation for urban development using multi-hazard assessment map

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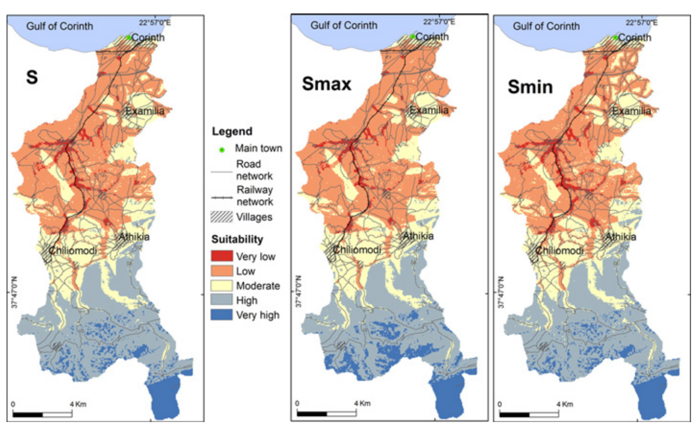
HIGHLIGHTS

- Individual landslide, flood and seismic hazard assessment maps are produced.
- Natural hazard maps are created and correlated via multi-criteria analysis.
- Suitable sites for urban development are selected using multi-hazard map.
- Suitable area for urban development is located in the southern part of the study area.
- Almost 40% of the urban area is located in the low to very low susceptibility zones.

GRAPHICAL ABSTRACT



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ABSTRACT

Preparation of natural hazards maps are vital and essential for urban development. The main scope of this study is to synthesize natural hazard maps in a single multi-hazard map and thus to identify suitable areas for the urban development. The study area is the drainage basin of Xerias stream (Northeastern Peloponnesus, Greece) that has frequently suffered damages from landslides, floods and earthquakes.

Landslide, flood and seismic hazard assessment maps were separately generated and further combined by applying the Analytical Hierarchy Process (AHP) and utilizing a Geographical Information System (GIS) to produce a multi-hazard map. This map represents the potential suitability map for urban development in the study area and was evaluated by means of uncertainty analysis.

The outcome revealed that the most suitable areas are distributed in the southern part of the study area, where the landslide, flood and seismic hazards are at low and very low level. The uncertainty analysis shows small differences on the spatial distribution of the suitability zones. The produced suitability map for urban development

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proves a satisfactory agreement between the suitability zones and the landslide and flood phenomena that have affected the study area. Finally, 40% of the existing urban pattern boundaries and 60% of the current road network are located within the limits of low and very low suitability zones.

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1. Introduction

Landscape of the Earth is a complex system and the result of interaction of several factors such as geomorphic process, climate, time and human activity. The latter have the ability to change the landscape. For instance, deforestation or man-made constructions cause the increase of soil erosion and the transportation of the sediments, result in land degradation and have impact on flooding. On the other hand, landscape of the Earth has undergone significant morphological changes affecting human life. For instance considerable morphological changes in landforms due to active tectonics or changes in climate control human activities (Cerdà, 1998; Bathrellos et al., 2014; Comino et al., 2015; García-Ruiz, 2015; Ochoa-Cueva et al., 2015; Serrano-Muela et al., 2015; Skilodimou et al., 2014; Torres et al., 2015).

Events such as landslides, floods and earthquakes are physical phenomena, active in geological time. These phenomena have affected the natural environment and existing biota, even before the appearance of man on Earth. Nowadays, they are considered as natural hazards and an important global problem threatening human life.

Natural hazards are events, capable of producing damage to the natural and man-made environment. Moreover, their impact differs from place to place and frequently these natural phenomena appear to have adverse long-term effects due to their associated consequences. When these consequences have a major impact on human life and activities, they become natural disasters (Alcántara-Ayala, 2002; Slaymaker, 1997). Thus, consideration of the physical environment and its influence in landscape evolution is essential to gain insight into the relation of the magnitude and the occurrence probability of natural hazard. Moreover society is becoming increasingly aware of the human intervention in natural environment which often lead to natural disasters that result in the loss of human life and property, and important economic repercussions (Biswas et al., 2015; Martínez-Graña et al., 2015; Strohmeier et al., 2016; Weinzierl et al., 2016).

Generally, natural disasters occur more frequently in relation to our capability to restore the effects of past events (Guzzetti et al., 1999). Therefore, in order to minimize the loss of human life and reduce the economic consequences, proper planning, and management of natural disasters are essential. However it is very important to take into account of the natural hazard predictive maps during the land use planning stage.

Currently, maps often show the spatial pattern of a natural phenomenon, environmental element or some human activity. Thus, they are crucial tools for several scientific disciplines. For example maps are commonly used in studies of land degradation, land cover changes, environmental impacts, natural hazard assessment and site selection (Bathrellos et al., 2008; Fava et al., 2016; Holleran et al., 2015; Jafari and Bakhshandehmehr, 2016; Miller et al., 2015; Papadopoulou-Vrynioti et al., 2013a; Soulard et al., 2016; Xu et al., 2015; Yuan et al., 2016). Maps that provide information on the spatial distribution of natural hazards such as landslides, floods and earthquakes are important tools for planners and environmental managers when selecting favorable locations for land use development (e.g. Bathrellos et al., 2009; Chousianitis et al., 2016; Das et al., 2013; Guzzetti et al., 1999; Hopkins, 1977; Rozos et al., 2013; Skilodimou et al., 2003; Youssef et al., 2015). In recent decades, Geographical Information Systems (GIS) is commonly used in estimation of various natural hazard phenomena and land use planning (Burger, 2008; Chen et al., 2003; Collins et al., 2001; Svoray et al., 2005; Papadopoulou-Vrynioti et al., 2014).

Since natural hazards are complex phenomena, to date several studies have focused on one hazard event and a single hazard map. But, one region may suffer from more than one natural hazard. According to the Organization of American States (Bender, 1991) the use of a single hazard map to provide information on each hazard, may be confusing for planners due to the high number of maps and their possible variance in the area covered or the scales used. Alternatively, a map arises from the synthesis of multi-hazard maps, including different hazard-related information for a particular area helps the planners to analyze all of them. Moreover, characteristics of many hazards and the possible trigger mechanisms of each one may be composed at the same time. Multi-hazard map is an excellent tool for selection of appropriate land uses and assessing vulnerability and risk of urban areas. It has become essential in natural hazard mitigation and urban disaster management. The United Nations (UN, 2002) has emphasized the significance of multi-hazard assessment and referred that it “is an essential element of a safer world in the twenty-first century”. However, multi-hazard analysis is a complex task and poses a lot of challenges regarding multi-hazard assessment, along with the examination of vulnerability and risk level (Kappes et al., 2012). In this context, various studies have concentrated on multi hazard assessment using GIS-based methods that allowed the analysis of the different data, the development of natural hazard models and the estimation of vulnerability and risk for a particular region (i.e. El Morjani et al., 2007; FEMA, Federal Emergency Management Agency, 2004; Kappes et al., 2011; Schmidt et al., 2011; van Westen et al., 2014).

There are various heuristic, statistical, and deterministic approaches that can be applied in natural hazard estimation and land use suitability analysis (e.g. Assimakopoulos et al., 2003; Ayalew and Yamagishi, 2005; Guzzetti et al., 1999; Papadopoulou-Vrynioti et al., 2013b). One popular deterministic method is the Analytical Hierarchy Processes (AHP) that is considered as a multiple objective decision making method and was developed by Saaty (1977). The AHP is a weight evaluation process that combines qualitative and quantitative factors for ranking and evaluating alternative scenarios, among which the best solution is ultimately chosen (Saaty, 1990; Saaty, 2004). Thus, an integrated approach of AHP within a GIS environment has gained wide application in the assessment of a single natural hazard (Fernández and Lutz, 2010; Karaman and Erden, 2014; Rozos et al., 2011), and of multi-hazard (Peng et al., 2012; Karaman, 2015), along with site selection and land use suitability analysis (Bathrellos et al., 2012; Baja et al., 2007; Dai et al., 2001; Marinoni, 2004; Panagopoulos et al., 2012; Thapa and Murayama, 2008; Youssef et al., 2011). However, the AHP method has some disadvantages originating the decision-making process. One of the important problem of the method is the inability to determinate the uncertainty which may happen from selection, comparison and ranking of multiple criteria (Bathrellos et al., 2013; Nefeslioglu et al., 2013).

In the present study landslide, flood and seismic hazard maps were produced and used to estimate and select suitable areas for urban development. The AHP method and GIS were implemented to support the processing and the evaluation of the factors used in the assessment of the three aforementioned geohazards within the study area. In the second stage, using the landslide, flood and seismic hazard maps derived in the previous step, the AHP method was further applied with the aim of producing the final hazard zonation map and facilitating the identification of suitable sites for urban development. Since the method has not the capability of recognizing the uncertainty associated with spatial outputs, a sensitivity analysis of the three hazard maps was performed.

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