Hazard maps for flash-floods in the Thriassion Plain

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Abstract

A geohazard is defined as an environmental condition that has the possibility of growing into a critical event. Of all geohazards, flooding is the most common and costly. The Thriassion plain has been affected by several storm flood events, causing serious hazard to life and destruction of buildings and infrastructure.

The purpose of this study is to develop a GIS-aided flood hazard zoning of the area of the Thriassion plain applying Multicriteria Decision Analysis (MCDA). The model incorporates four parameters: the distance to the stream channels, slope, cover type and soil type. The weight and rank values are assigned to the layers and to the classes of each layer respectively. The assignment of the weight/rank values and the analysis are realized by the application of two different decision models, namely Multi Attribute Utility Theory (MAUT) and Analytic Hierarchy Process (AHP) methods.

A hazard map for each method is obtained using an algorithm that combines factors in weighted linear combinations. The flood hazard maps that prepared as outputs of these methods are found to be consistent with each other and show that the southwest part of the Thriassion plain and also the areas close to the streams have the highest flood hazard over an extended area as consequence of the conjunction of lowlands, with slopes under 2%, and the presence of stream channels. Finally a map including hazard map overlapped by the local infrastructures also was created.

Keywords
Floods, Thriassion plain, Hazard, GIS, Multicriteria Decission Analysis

Introduction

Flooding is regarded as one of the most dangerous natural hazards and as a principal trigger of disasters (Alcantara-Ayala, 2002). Flash floods are one of the most significant natural hazards in Europe, causing serious hazard to life and destruction of buildings and infrastructures. For this reason, European Community adopted the Directive 2007/60/EC, known as the Floods Directive. The purpose of it is to establish a framework for the assessment and management of flood hazards, aiming at the reduction of the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods in the Community.

The hazard of flooding is defined as a function of both the probability of a flood happening and its impact (Fernandez & Lutz, 2010). Flood hazard management can be roughly divided into two parts (Schanze, 2006): Flood hazard analysis & assessment on the one hand and hazard mitigation on the other. Broadly speaking, the purpose of flood hazard assessment is to establish where hazard is unacceptably high, i.e. where mitigation actions would be necessary.

Susceptibility analysis for an area often requires an enormous amount of data which must be geographically related to one another. Geographical Information Systems (GIS), being a computer-based system that enables acquisition, storage, retrieval, modeling, manipulation and analysis of geographically related data (Aronoff, 1993; Worboys, 1995), has proved a powerful tool for managing large amount of data involved in multiple criteria analysis.

GIS should be considered as a special-purpose digital database in which a common spatial coordinate system is the primary means of storing and accessing data while processing the data to obtain information for decision making. The ultimate aim of GIS is to provide support for decision making (Densham, 1991). This can be achieved by integrating the MCDA and the analytical capabilities of GIS (Carver, 1991; Eastman et al., 1995; Malczewski, 1999).

There is plenty of literature on multicriteria analysis or multicriteria decision-making in general (Bana E Costa 1990; Zimmermann & Gutsche 1991; Vincke 1992; Munda 1995; Belton & Stewart 2002). Most of these textbooks set the focus on the mathematical core of MCA, the decision rules and the various approaches and methods existing (MAUT, Outranking, AHP etc.). Spatial MCA, in contrast, is a relatively new but growing research field which is still developing with the further improvement of GIS (Malczewski 2006).

The application of MCA in general and especially spatial MCA in the context of flood hazard management is still rare (Meyer et.al., 2007). In the UK a report on the applicability of MCA procedures in the common BCA appraisal technique for flood hazard management measures was written by RPA (2004) for the responsible state department DEFRA. Also the official manual for damage evaluation in the UK (Penning-Rowsell et al. 2003) includes a section on multi-criteria evaluation of flood protection measures. Both are based on MAUT approaches. However, these studies focus on methodologies to incorporate multiple stakeholders' opinions in multi-objective decision-making and do not consider the spatial dimension of flood hazard.

Only very few examples for the application of spatial MCA in the field of flood hazard analysis and management exist. For example Tkach & Simonovic (1997), analyze the spatial distribution of the multiple effects of different flood protection alternatives in the Red River Basin, using a GIS-based variant of the Compromise Programming (CP) MCA-technique which they call Spatial Compromise Programming (SCP).

Furthermore, the selection of appropriate evaluation criteria is an important step of MCA. Besides the publications on the flood hazard problem mentioned above there are also some publications with no particular MCA-background which give a good overview over potential criteria.

The purpose of this study is to present a flood hazard map using MCDA techniques with GIS support in order to define areas with the highest hazard factors (most likely to flood).

Study area

The Thriassion plain (Fig. 1) is one of the most rapidly growing regions in north-western prefecture of Attica. The principal urban centers included in the study area are the city of Eleusis and the towns of Aspropyrgos and Magoula. These cities have joint population of 60.300 inhabitants. The Thriassion plain bordered at north by mountains and hills and at south by the Gulf of Eleusis. An extended area at the south of the Thriassion plain presents slope fewer than 2%. The majority of the study area is rural except from some north parts with forests and the southern part in which the city of Eleusis is located and thus it can be characterized as urban.

The area under study experiences a typical Mediterranean climate. The average annual rainfall over the area is around 350 mm and the average temperature is around 18ºC but during summer, it ranges from 36 ºC to 43 ºC. The study area consists largely of alluvial fans at the center area, limestone is observed at the north part of the Thriassion plain and alluvium stones at south in the lower reaches of the stream channels.

The main stream channels that must deal with runoff water in the area characterized by three principal channels: one at the east, called Remataki, one at the center, which is Giannoula and one at the west which named Sarantapotamos. These stream channels cross the Thriassion plain leading water to the Gulf of Eleusis. There is also a secondary system made up of small channels and streams that leading water to the main discharge channels.

In recent years, records have shown that, most flooding events occurred because stream channels cannot drain effectively into an outfall. Consequently, excess water flows down roads and other paths of lesser resistance flooding low-lying areas. A flood with that characteristics occurred in February 1978.

In January 1996 intense storms caused high peak flows which exceeded channels capacity, flooding city streets. The city of Eleusis remained flooded after storms because streams overflowed and most of the ground was highly compacted.

One more flood characteristic of the Thriassion plain area is that water rises quickly and flows with high energy through the channels due to steep slopes, but the rain water flows down rapidly to the lowland areas.

Flooding may takes a high toll in damage, distress, and even human lives. Storm events occurred in January 1996 causing the death of two people, the evacuation of several families and great damage to the infrastructures (Nikolopoulos, 2004).

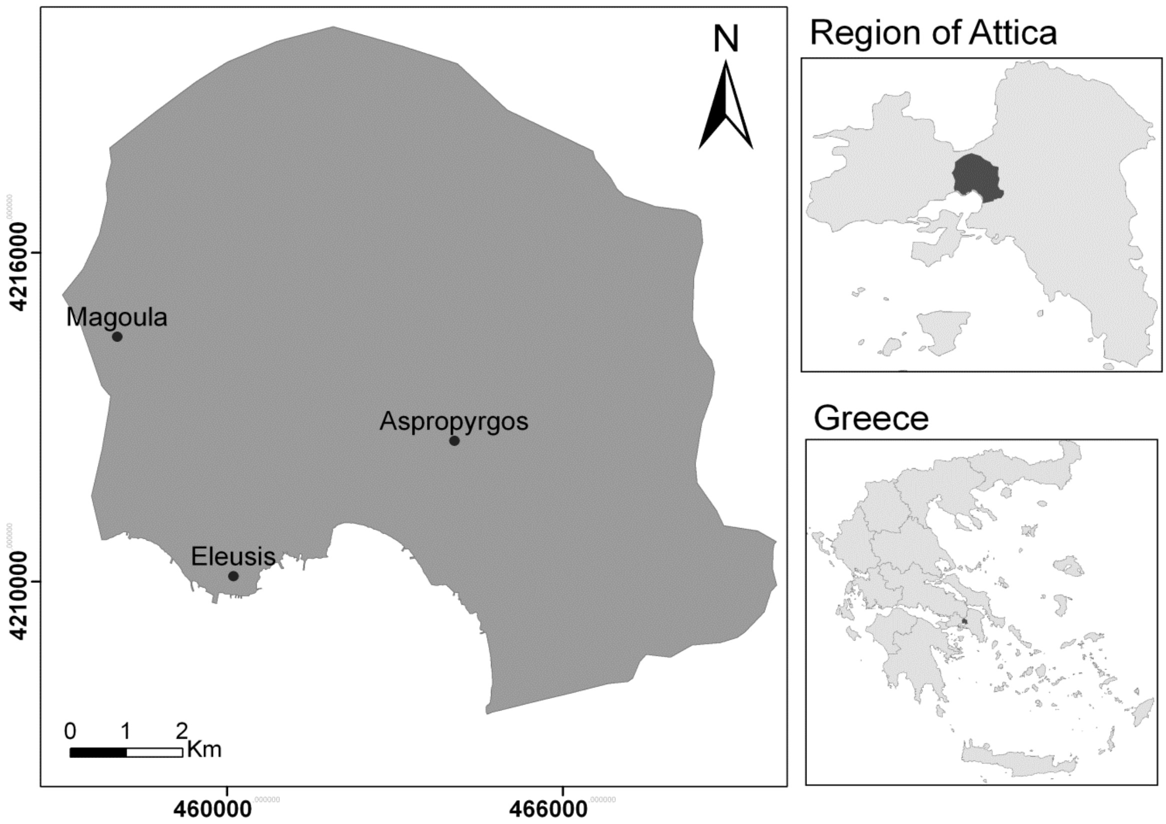

Figure 1: Location map of the study area

Methodology

Steps followed in this study are presented in Figure 2, which includes primary data used, their manipulation in a GIS environment and multicriteria decision analysis.

Three main data sources were used for the base cartography: a detailed digital elevation map, a lithological map and land cover map. Four different predictor maps were produced from these three data sources. These were: slope, distance to the discharge channels, geology, and cover type layers. The next step was to assign weight and rank values to the layers and to the classes of each layer, respectively. The assignment of the weight/rank values and their analysis were realized by the application of two different decision models, namely the Multi Attibute Utility Theory (MAUT) and the Analytic Hierarchy Process (AHP) methods.

This flowchart can be applied for further similar studies, provided that the layers used for the analysis are determined according to the needs of the study area.

From the various multicriteria methods mentioned above was chosen approach MAUT and AHP for studying flood hazard in the Thriassion plain.

<u>MAUT</u>

The general concept of additive MAUT approaches is to generate a weighted average of the single criterion values for each alternative. Given a set of evaluation criteria and a set of alternatives to be compared as well as scores for each alternative in each criteria and a set of weights for each criterion the procedure for this is the following (Meyer et.al., 2007):

1. Standardize the criteria scores to values (or utilities) between 0 and 1.
2. Calculate the weighted values for each criterion by multiplying the standardized value with its weight.
3. Calculate the overall value (utility) for each alternative by summing the weighted values (utilities) of each criterion.
4. Rank the alternatives according to their aggregate value (utility).

The general model for this would be

$$U_i = \sum_j W_j * U_{ij}$$

where Ui is the overall value or utility of the alternative i, uij is the value or utility of the alternative i regarding criterion j and wj is the standardized weight for criterion j.

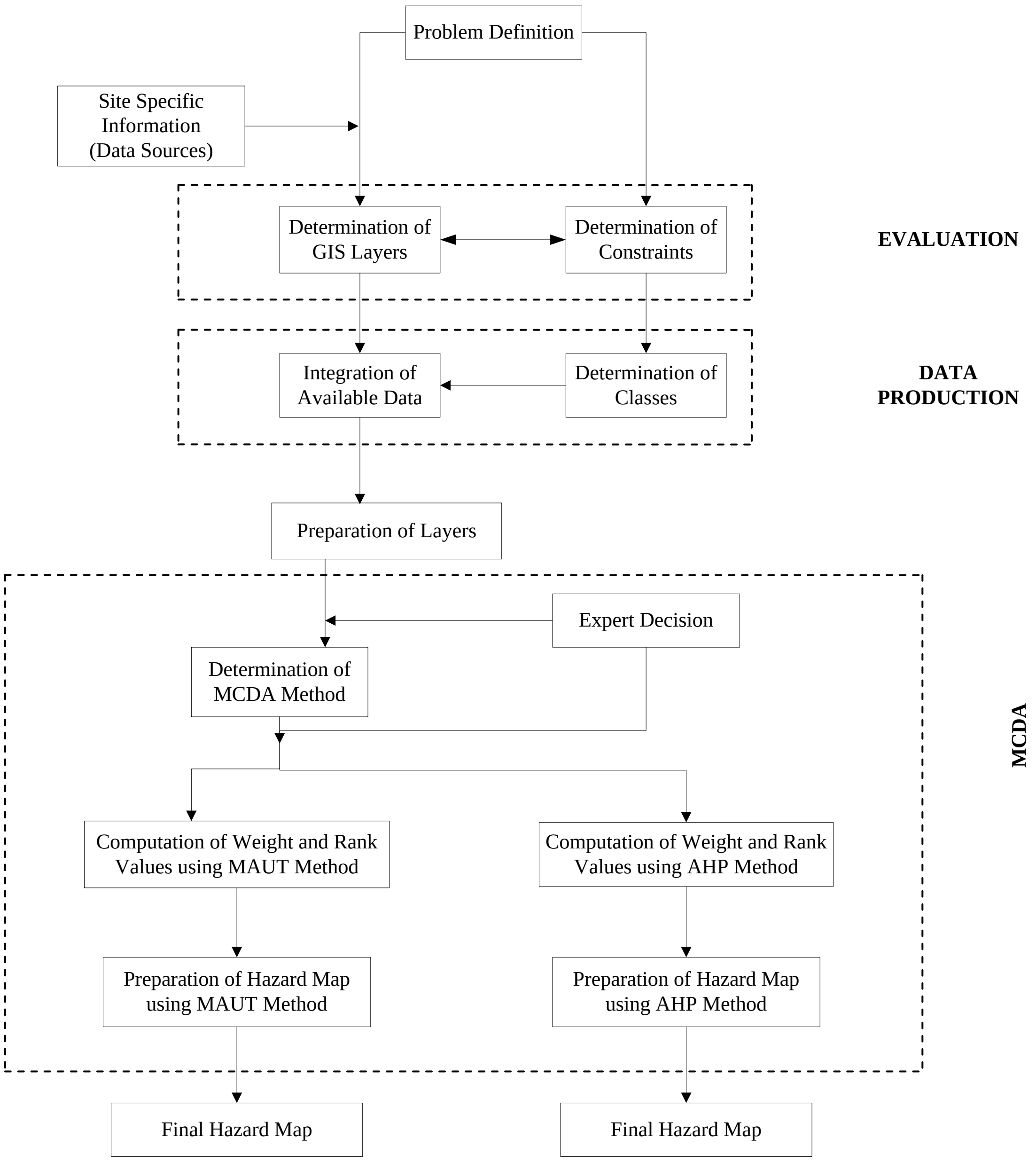

Figure 2: Flowchart for the preparation of flood hazard map

Apart from this general procedure there are different approaches, especially concerning the method of standardizing the criteria scores (which leads to clear differentiation between the terms “score”, “value” and “utility”).

In the simple additive weighting approach the criteria scores are standardized by a linear scale transformation. This can be achieved for example by either dividing each score by the maximum score (maximum score approach) or, alternatively, by dividing the difference of each score to the minimum score by the score range for that criterion (score range approach).

In the swing weight approach the criteria scores are standardized by dividing each score by the sum of the scores.

The formula for the maximum score approach is

$$X'_{ij} = \frac{X_{ij}}{X_j^{max}}$$

for the score range approach

$$X'_{ij} = \frac{X_{ij} - X_j^{min}}{X_j^{max} - X_j^{min}}$$

And for the swing weight approach

$$X'_{ij} = \frac{X_{ij}}{\sum X}$$

with
x´íj : standardised score
xíj : criterion score
xmax : maximum criterion score
xmin : minimum criterion score
∑X :sum of the scores

In this study the scores of classes are standardized by the maximum score approach and the score of criteria are standardized by the swing weight approach.

<u>AHP</u>

The AHP method is a multi-objective, multicriteria decision making approach that employs a pair-wise comparison procedure to arrive at a scale of preferences among a set of alternatives (Saaty, 1977).The AHP uses a fundamental scale of absolute numbers to express individual preferences or judgments. This scale consists of nine points, chosen because psychologists conclude that, nine objects are the most that an individual can simultaneously compare and consistently rank (Saaty, 2008). Pairwise judgments are made based on the best information available and the decision maker's knowledge and experience.

The AHP also provides mathematical measures to determine inconsistency of judgments mathematically. Based on the properties of reciprocal matrices, consistency ratio (CR) can be calculated. In a reciprocal matrix, the largest eigenvalue (λmax) is always greater than or equal to the number of rows or columns (n). If a pair-wise comparison does not include any inconsistencies, λmax=n. The more consistent the comparisons are, the closer the value of computed λmax to n. A consistency index (CI) that measures the inconsistencies of pair-wise comparisons can be written as:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

and a measure of coherence of the pair-wise comparisons can be calculated in the form of consistency ratio (CR)

$$CR = \frac{CI}{RCI}$$

where RCI is the average CI of the randomly generated comparisons (Tab. 1). A consistency ratio of the order of 0.10 or less is a reasonable level of consistency (Saaty, 1977). A consistency ratio above 0.1 requires revisions of the judgments in the matrix because of an inconsistent treatment of a particular factor rating.

Table 1: RCI values for different values of *n*. (Data Sources: Triantaphyllou & Mann, 1995)

n	1	2	3	4	5	6	7	8	9
RCI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

Hazard maps development

Rainfall and subsequent runoff are the key variables behind flash floods, but the other variables considered to boost flash floods are drainage network characteristics, catchment morphology, and a catchments' response to runoff (Youssef et.al. 2011). Studies have shown that channel size and geometry can be used to characterize drainage processes as these relationships have been found to be significant (Wharton 1992). Furthermore, studies also suggest that catchment response to flash floods is dependent on parameters such as initial soil wetness, slope, catchment roughness and ratio of impervious to pervious surfaces (Liu et.al. 2006).

GIS provides tools which enable creation and analysis of digital elevation models (DEM) can be used for deriving hydrological characteristics such as flow direction, flow accumulation, watershed boundaries, stream order, and several other catchment characteristics. Some of these characteristics can be validated by analyzing aerial photographs or satellite images (Liu et.al. 2003). Aerial photographs or high resolution satellite images taken during a flood event can further be used for validating the predicted flooding extents by comparing the analysis with the observed flood extent.

Determining catchment characteristics using the previously mentioned data sets provides insight into water flows through the catchment. Furthermore, impervious surfaces, vegetation and soil types within the catchment influence rainfall runoff and drainage patterns, and such surfaces can be easily derived from remote sensing images. The steepness of the slope contributes to the amount and velocity of runoff that may be further affected by man-made structures such as drainage and road networks. Urban development may create changes in hydrological characteristics by the blocking of natural flow paths potentially creating excessive runoff in other areas within the catchment.

Most of the GIS software packages can derive various catchments morphometric parameters from a DEM (Forte et.al. 2006; Youssef et.al. 2011) and this is best achieved through the use of highly accurate and high resolution DEM (Liu et.al. 2011).

The DEM offers an excellent alternative for automating the delineation of flow channel networks using an algorithm that derives flow direction and flow accumulation (Fig. 3) (Moore et.al. 1991). Such drainage channel networks are derived based on the assumption that water flows in response to gradients in gravitation potential energy. Using a DEM has the advantage of potentially identifying drainage paths not easily identifiable in remote sensing images (Forte et.al. 2006). Slope can also be easily derived from a DEM, and this has been a widely used topographic attribute for informing land use classes together with other drainage factors (Srivastava & Lees, 2007). Derivatives such as catchment relief and mean sub-catchment slope can be related to the occurrence of flash floods. Another important parameter derived from a DEM are catchment boundaries by using different threshold values to define contributing areas, thereby enabling the derivation of multiple spatial layers showing nested sub-catchments at different scales. These sub-catchments can subsequently to assigned attributes of various morphometric and physical characteristics for the catchment.

To evaluate the extent of flooding at the study area the model incorporates four variables: Distance to the stream channels, slope, soil type and cover type. These variables were selected based on their relevance with respect to the flood susceptibility of the study area and the quality of the data sets that were available. The relevance of the variables and their classification in classes is described below.

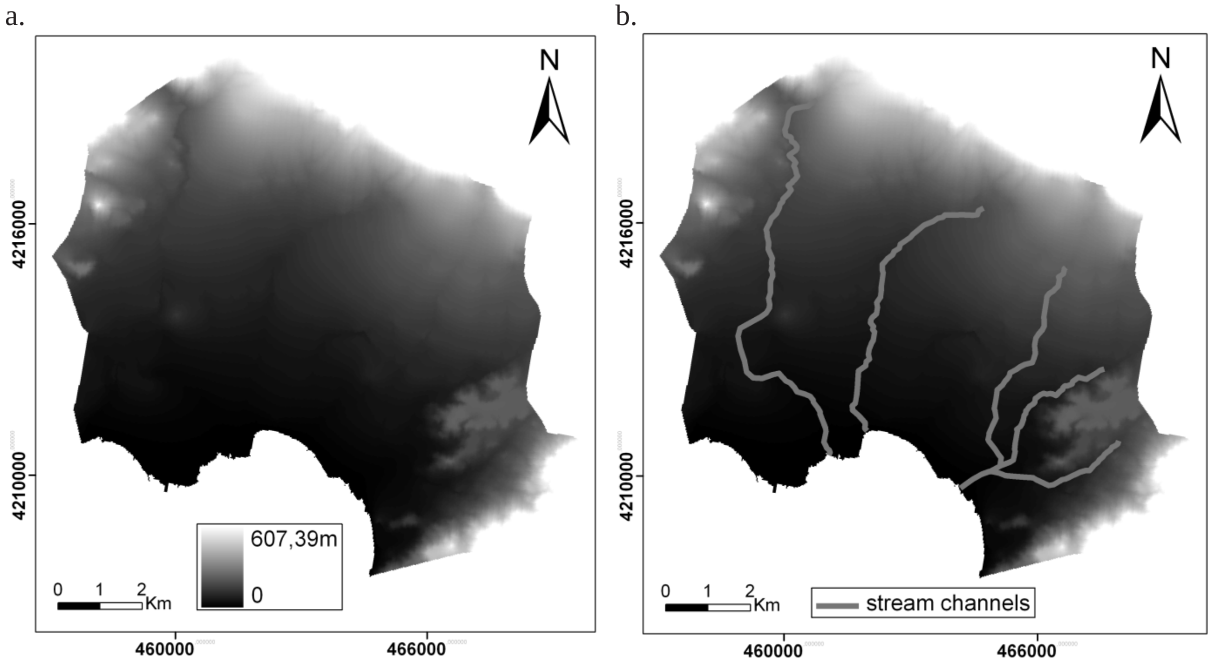

Fig.3: a. The Digital Elevation Model (DEM) of the study area, b. The main Stream Channels of the study area (they were derived through the hydrologic analysis of DEM)

Slope

Slope is an important factor to identify those zones that have shown high susceptibility to flooding over the years due to low slope gradient. The slope of the land in the watershed is a major factor in determining the water velocity. Thus, on very flat surfaces where ponding areas occur, a considerable amount of the surface runoff may be retained in temporary storage.

The general direction of runoff in the study area is north to south and slopes varies from more than 15% along the northern border to less than 1% in the south part of the area. The slope map (Fig. 4a) was prepared in percent grade using the DEM of the study area. The values were subdivided into four classes as shown in Table 2.

Distance to the stream channels

Distance to the discharge channels has great importance in the case of the Thriassion plain. According to the records from the local authorities, the most affected areas during floods are those near these channels, as a consequence of overflow. This layer was created using a multi buffer operation identifying all areas within the specified distances from the channels (Fig. 4b).

The distance intervals used were: <100 m, between 100 and 200 m and between 200 and 300 m. The main stream network became as a combination of the level of flow accumulation and the observation of the DTM (Digital Terrain Model). The flow direction and flow accumulation level was derived through the hydrologic analysis of DEM with the tools that GIS gives.

Cover type

Impervious cover (buildings, roads, and parking lots) reduces infiltration capacity and runoff from paved areas can add substantially to total runoff. Urbanization typically leads to a decrease in lag time, an increase in the peak discharge, and an increase in the total discharge for a particular flood (Murck et.al. 1996).

The cover type layer (Fig. 4c) was given from the Ministry of Rural Development and Food and the cover type description was made following the Corine code system. According to these procedures the study area was subdivided into: rural districts (corps), urban districts (residential, commercial, business and industrial) and woodland.

Lithology map and soil layer

The soil layer of the study area was based on the lithology map and on the report prepared by Special Secretariat for Water (Fig. 4d). For the study area, some lithological units were identified. These units were classified in three main categories Alluvium, Limestone and Alluvial fans.

Each geological type categorized according to the liquid permeability that presents. Thus, Alluvial fans characterized by high permeability, Limestone present moderate permeability, while Alluvial is almost impermeable.

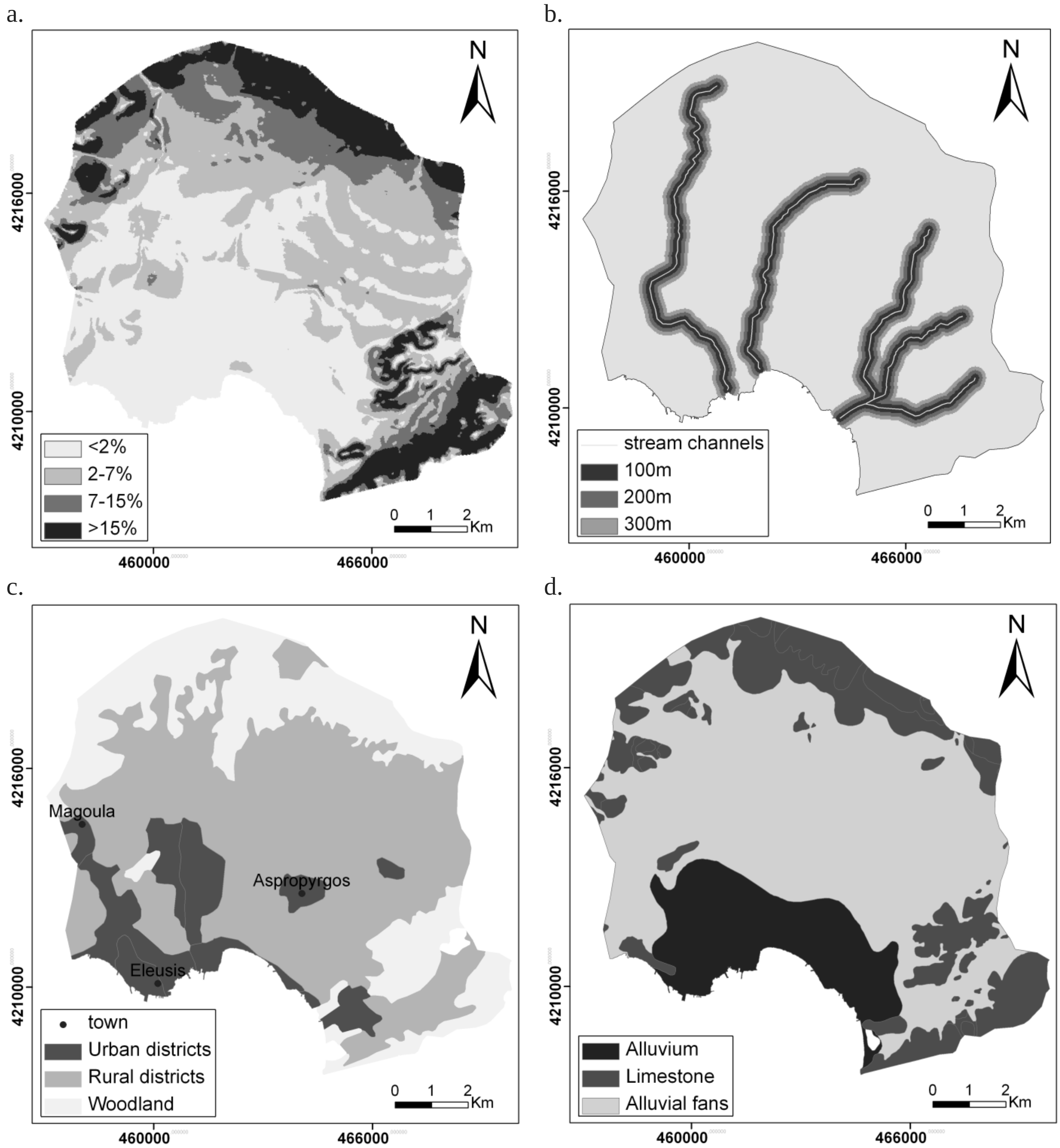

Fig. 4: a. Slope map of the study area, b. The map of the distance to the stream channels, c. The cover type map of the study area, d. The soil type map of the study area

Development of weights

The basis for the two analytical models, MAUT and AHP, was to identify areas susceptible to flash flooding. During the analysis, with both approaches, weight values were assigned to the layers and rank values to the classes of each layer according to their importance in the case study of area floods.

For each class of the layer, rankings were given according to their significance in foundation performance. After the rankings were assigned to the classes of each layer, the weights were assigned to layers according to their importance. The interaction between the layers was not taken into consideration since the layers were assumed to be independent of each other. The assigned weight and rank values for the layers/classes of the study area based on the local characteristics of each layer and engineering judgment are given in Table 2.

The most important layer according to weight was defined as the slope layer due to its importance in the accumulation and discharge of the water. Distance to the discharge channels is next; because the historical review of flood events shows that areas near the channels are highly affected as a consequence of their overflow. The cover type and soil type follow in decreasing order of importance. As to class ranking, classes decrease in order from 1 to 0 as the least favorable to flooding or best locations to least likely to experience flash flooding.

The weight and rank values of the layers and classes of each layer were standardized in order to obtain a common dimensionless unit. Afterwards, the output (flood hazard map) was created by multiplying the weight value assigned to each layer by the rank value given to the classes of that layer and finally by adding up the products. The steps that are followed to each approach are the one that described above, at Methodology chapter.

For the preparation of the map with the susceptible of flooding areas, the overlapped operations of the layers were used.

The formula proposed by Malczewski (1999) for obtaining the total scores was applied in this study. Accordingly, each pixel of the output susceptibility map (Mi) was calculated by using the following summation:

$$M_i = \sum_j w_j x_{ij}$$

where, xij=rank value of the i class with respect to the j layer
wj=normalized weight of the j layer.

Thus the normalized weight value assigned for each layer was multiplied by the standardized rank value given to the classes of that layer. Finally the sum of the products was calculated.

The final map we took from each approach (Fig. 5) determines the areas that are susceptible at the event of flooding and were categorized in five resultant classes as: Very High (VH), High (H), Medium (M), Low (L) and Very Low (VL).

The computed weight and rank values are given in Table 2.

Have to be mentioned that in the AHP method, the consistency ratios for all of the pair-wise comparisons used to obtain the flooding hazard map were calculated and found to be consistent.

Table 2: Assigned weight and rank values for the layers/classes of the study area

Layers/ Criteria	Weighting		Classes	Ranking	
	MAUT	AHP		MAUT	AHP
Slope	0.34	0.576	0-2%	1	0.5345
			2-7%	0.74	0.3040
			7-15%	0.53	0.1075
			>15%	0.11	0.0540
				Inconsistency ratio:	*0.04*
Distance to the stream channels	0.28	0.288	100m	1	0.6807
			200m	0.71	0.2014
			300m	0.23	0.1179
				Inconsistency ratio:	*0.02*
Cover type	0.24	0.087	Urban districts	1	0.7644
			Rural districts	0.47	0.1658
			Woodland	0.08	0.0698
				Inconsistency ratio:	*0.05*
Soil type	0.14	0.049	Alluvium	1	0.7482
			Limestone	0.59	0.1804
			Alluvial fans	0.22	0.0714
				Inconsistency ratio:	*0.03*

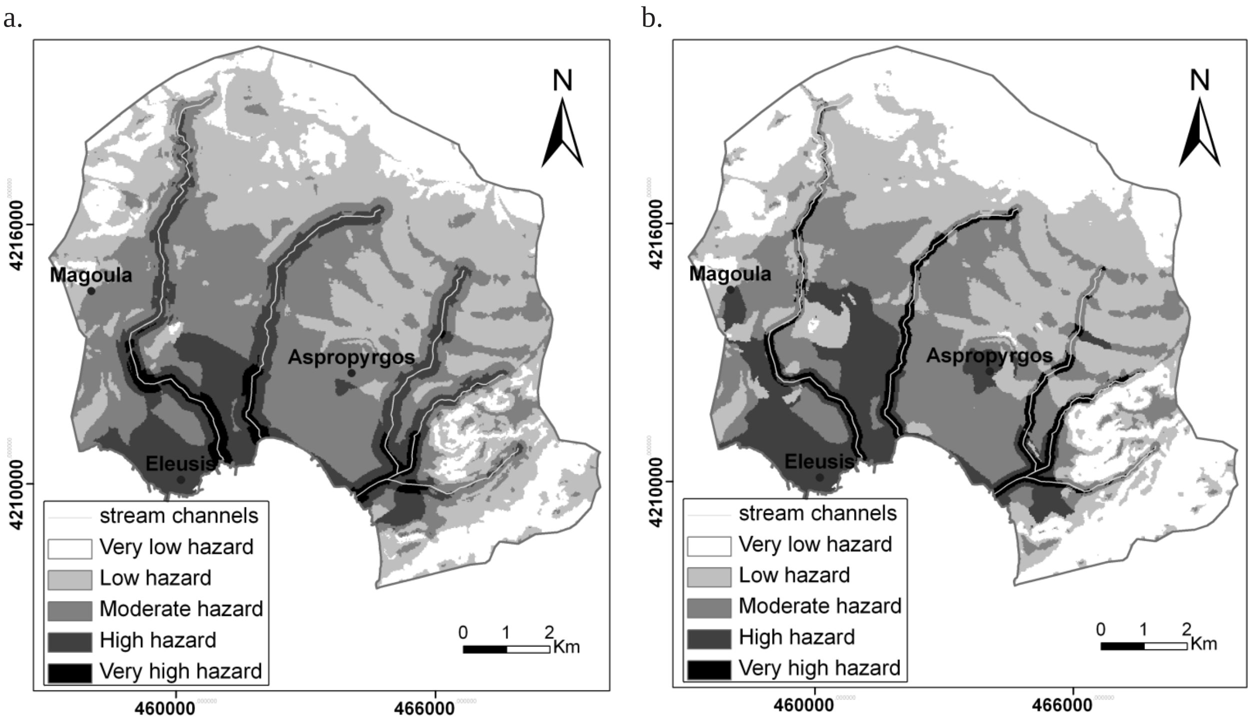

Fig. 5: a. The flood hazard map prepared by using the MAUT method, b. The flood hazard map prepared by using the AHP method

Discussion

Multiple objectives are essential to many 'real' systems. Frequently, these multiple objectives conflict with each other (as one objective is improved, the others may deteriorate). Dimensional analysis can help the decision maker to make better decisions under such circumstances (Starr & Stein, 1976).

In decision making context, a criterion would imply some sort of standard by which one particular choice or course of action could be judged to be more desirable than another. Actually in real life, every decision requires the balancing of multiple factors so that in some sense, everyone is well practiced in multicriteria decision making. However, the human brain can only simultaneously consider a limited amount of information, so that all factors cannot be resolved in one's head(Belton & Stewart, 2002)

Usage of GIS based MCDA is essential in the preparation of hazard maps due to the need for using a large amount of spatial data and integrating the geographical data with the decision maker's preferences.

Two considerations are of critical importance for spatial Multicriteria Decision Analysis: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation and analysis, and (ii) the MCDA capabilities for aggregating the geographical data and the decision maker's preferences into uni-dimensional values of alternative decisions (Carver, 1991; Jankowski, 1995). Accordingly, the possible sources of errors in our study can be categorized as data related errors and errors resulting from the decision maker's preferences.

Considering the data related errors; the original DEM hasn't the highest accuracy and high resolution for such hydrological analysis. Furthermore, for the preparation of the data layers, the continuous surfaces are formed from the interpolation of this raw point/line data. During this interpolation process, some errors may have occurred due to lack of information between the consecutive points/lines.

In addition to the data related errors, there is uncertainty involved in the specification of decision make preferences. In fact, the criterion map errors and decision maker preference errors are interrelated. The information derived from criterion maps is an essential element for specifying the decision maker's preferences. For reliable results, the decision maker is expected to be an expert to make preferences since the importance of each criterion can be overestimated or under estimated according to these preferences.

The subjectivity of the preferences comes mainly from the assignment of weight and rank values. In the scope of this study, the weight and rank values which are used both in the MAUT and the AHP methods, are assigned properly according to the engineering judgment.

The basic differences between the MAUT and the AHP methods lie in their objectiveness, easiness and evaluation opportunities. Although AHP is more complicated than MAUT, AHP has more objective results. The basic strategy is to divide the decision problem into small, understandable and manageable parts; analyze each part; and integrate the parts in a logical manner to produce a meaningful solution (Malczewski, 1999). In the AHP method, this strategy is applied in assigning rank and weight values since only two layers/classes are considered and compared at a time. This decreases the subjectivity of the study and brings an advantage to AHP method.

Besides, the pairwise comparison for the determination of weights is more suitable than direct assignment of the weights, because one can check the consistency of the weights by calculating the consistency ratio in pairwise comparison; however, in direct assignment of weights, the weights are depending on the preference of decision maker (Sener et.al. 2006; Kolat et.al. 2006).

On the other hand, the MAUT method definitely has an advantage in rapidity. In applying this method, the result can be realized quickly with the contribution of a qualified expert. However, since MAUT method uses direct assignment of the weights/ranks, the qualification of the expert needed is much more than needed in AHP.

Conclusions

This study demonstrates the superiority of the usage of MCDA techniques with GIS for the preparation of the flood hazard map. The important advantages of using these techniques can be summarized as having relatively low cost, easy data manipulation, rapidly updating of data and the possibility to produce various new scenarios.

In this study, slope, distance to stream channels, soil type and cover type layers were prepared for the chosen study area, the Thriassion plain. The assignment of the weight and rank values and the analysis were performed by application of the MAUT and the AHP methods. As a result, the study area was categorized into five different zones determining the areas with very high, high, moderate, low and very low hazard. The boundary conditions for the categories were evaluated according to expert judgment, taking into consideration the score distribution of each class in a frequency histogram. The flood hazard maps obtained by using the MAUT and the AHP methods are found to be consistent with each other. The reason for this consistency lies in the proper assignments of weight and rank values by the expert.

The areas labeled in the map as very high hazard are strongly influenced by the slope and the distance of the stream channels according to the high weight given to these factors in the model. The assignment class is due to the great importance of both the slope and the drainage overflow in the worst flooding events that occurred in Thriassion plain.

The final map (for each approach) shows that the southwest part of Thriassion plain has the highest flood hazard over an extended area as a consequence of the combination of lowlands with slopes under 0.6%and the presence of stream channels. These areas consisted of important commercial enterprises and the city of Eleusis. On the other hand, the area with the lowest hazard is coincident with the hills that located to the north of Thriassion plain.
The major part of the study area corresponds to moderate and low hazard in the map.

According to the report that the Special Secretariat of Water prepared there are two points that shows the neighborhoods with the most important floods, which situated in areas that correspond to very high hazard in the map.

A new layer that illustrates the important Public buildings and big commercial enterprises of the area was created and overlapped on the analytical model output (Fig. 6). That helps to drawing up a plan to prevent and minimize the negative consequences of the flood.

The final flood hazard map is a tool for the area under study that may assist the planners and decision makers to drawing up a plan to reduce the vulnerability of the population to flood events. The map clearly shows that the neighborhoods located near the main stream channels are in danger. Highest-hazard areas are those in south-west including the city of Eleusis. These are characterized by the confluence of several channels, a lowland topography, and a gentle slope gradient.

The model should be used as a first-stage analysis in the problem of floods in the study area. More detailed models will require more reliable information about precipitation and flow peak discharges.

MCDA techniques within a GIS environment have proved to be powerful methods to generate hazard maps with a good degree of accuracy.

The judgment upon the acceptability of the model could be made using external information from ground-truth data. In this study, data provided by government authorities regarding neighborhoods affected by floods plotted over the final map showing a remarkable coincidence with the very high and high hazard areas.

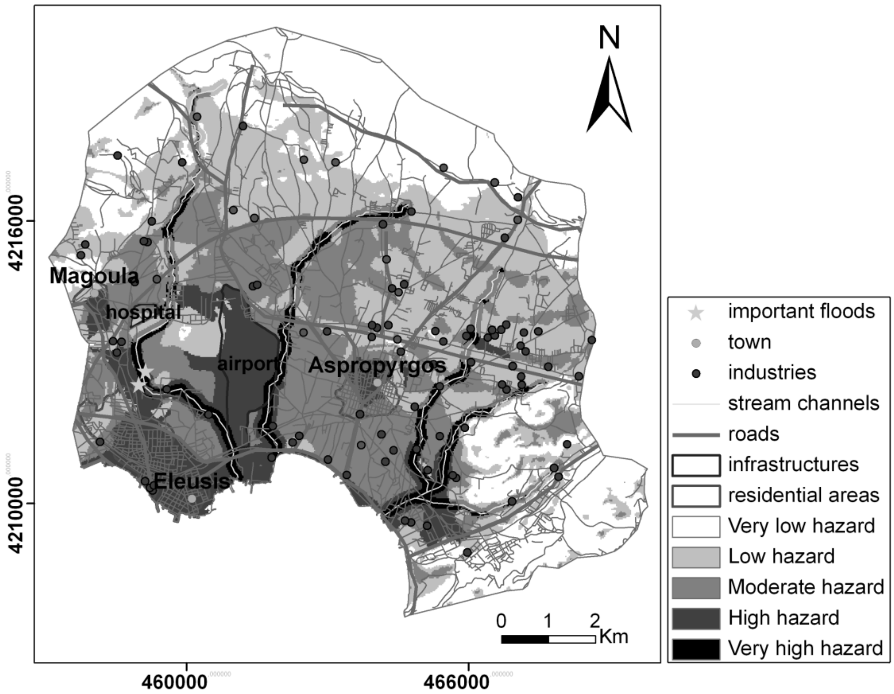

Fig. 6: The flood hazard map overlapped with the local infrastructures

Acknowledgments

The authors are thankful for valuable cooperation with the Ministry of Rural Development and Food and the Special Secretariat of Water. Thanks are also due to all the persons who contributed with their knowledge to our study.

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