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# FLOOD HAZARD ASSESSMENT BASED ON GEOMORPHOLOGICAL ANALYSIS WITH GIS TOOLS - THE CASE OF LACONIA (PELOPONNESUS, GREECE)

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## Abstract

The aim of the study was the development of a GIS tool, to be exploited eventually in the form of a WebGIS, as a decision support tool for flood hazard (and risk) assessment. The research was conducted in Laconia Prefecture in Peloponnesus. In this work, flood hazard assessment was implemented using hydrological models into a GIS environment (Arc Hydro model) taking into account the geomorphologic characteristics of the study area. More specifically, a DEM was used as input data of the Arc hydro model in order to produce the hydrographic network and the hydrological basins layer. For each basin, the morphologic characteristics such us area, mean slope, mean elevation and total relief, were calculated. These factors, all enhancing flood hazard, were combined in a product (by simple multiplication) in order to produce the inherent flood hazard map for each water basin and enhance the spatial differentiation of the phenomena. The final flood hazard map was produced by the combination of the aforementioned map and the slope map of the study area. The results of the followed methodology were evaluated using recorded flood incidents of the study area and shown that 60% of the incidents were related with the predicted high flood risk areas, which can be considered very high, once many of the flood phenomena in the non-predicted areas were largely due to previous human activity at the sites. Ultimately, the flood hazard map was published into a web GIS environment providing a friendly GUI to the end users. Except of analyzing the static flood hazard map, the end user have also the potential to interact dynamically with the map, adding to model calculation the meteorological factor (e.g. rain intensity, mean precipitation) in order to reassess the flood hazard of the study area.

**Keywords:** Flood hazard assessment, geomorphological analysis, WebGIS, Arc Hydro Model.

## 1. INTRODUCTION

Natural disasters occurring all over the world have a tremendous impact on regional and global environment and economy. In recent years, disaster phenomena are believed to increase due to human activities and/or climate change. The importance of natural hazards in terms of prevention, reduction and mitigation has been brought forward by international organizations such as United Nations through the development of a framework, the International Strategy for Disaster Reduction (ISDR), aiming at the worldwide reduction of vulnerability and risk.

Natural disasters occur worldwide; however their distribution around the globe varies regarding type, frequency of occurrence and impact. According to the registered disaster data, between 1900 and 1999, 13% of the total number occurred in Europe, whereas the greatest percentage (42%) was recorded in Asia. In the European territory, 27% of the total disaster incidents of that period are related to flood phenomena [1]. As a result, the Directive 60 of 2007 was released in the EU, to deal with flood management and achieve Flood Risk Reduction in the European Union, in connection and supplementary to the 2000/60 Directive for Water Management, also implemented by member countries. Flood Hazard and Flood Risk maps are now considered a prerequisite for flood management, throughout the EU in this framework.

In Greece, during the 20th century, earthquakes are the most often natural disaster. More specifically, between 1900 and 2004, earthquakes contribute the 35% of the total number of disasters, when floods and wildfires follow with 17% and 10% respectively [2]. In 2007 a major part of Peloponnesus region (Southwest Greece), and large areas of Laconia prefecture within it, was seriously affected by forest fires, thereafter associated with landslides and flood incidents that occurred since in the region.

In literature, research works dealing with natural hazards focusing on understanding natural processes, analysis and forecast of hazards such as flooding, mass movement, earthquakes and volcanism, can be found. According to Alcántara – Ayala [1] there are innumerable works related to natural hazards such as flooding associated with hydrometeorological phenomena namely tropical storms, hurricanes etc.[3]; approaches of fluvial flooding processes understanding [4, 5, 6]; flood simulations [7, 8, 9] and forecasting [10]; mass movement including landslide hazard analysis [11] and assessment [12, 13] as well as volcanic [14] and seismic hazards [15].

The integration of GIS into hazard mapping and disaster decision support has been continually upgraded and widespread since 2000, as a result of the increased availability of spatial databases and GIS software [16]. Several studies are cited in the literature, relating to flood hazard mapping and zonation using GIS [17, 18, 19, 20, 21] and/or remote sensing [22, 23, 24]; integration of GIS with hydrological models [25, 26, 27, 28] and flood mitigation and management decision support systems through GIS [29, 30]. Also, web based GIS application regarding natural hazard assessment; monitoring and forecasting were developed [31, 32, 33, 34, 35] providing advantages against the conventional systems such as ease of data sharing across an organization; dissemination to the public; simple graphical user interface(GUI) and cost effective tools.

The aim of the study was the development of a GIS tool to be exploited through a WebGIS as a decision support tool in relation to the flood hazard (and risk) assessment. The specific objectives were i) to estimate and map flood hazard using hydrological models into a GIS environment (Arc Hydro model) on the basis of geomorphologic data , and ii) the development of a friendly GUI via Web GIS application.

## 2. METHODS

### 2.1 Study area

The research was conducted in Laconia Prefecture (Peloponnesus, SW Greece). The area of Laconia Prefecture is about 3.621 Km$^2$ with mean elevation of 460m above sea level and maximum altitude of 2500m (Taygetos Mt.). The dominant hydrological feature of the area is the basin of Evrotas River, bounded to the east and west by the mountains of Parnon and Taygetos, respectively (Fig.1). This 1.700 km$^2$ watershed covers most of the central and northern part of the prefecture (including the city and the plains of Sparta) and Evrotas R. discharges in the Laconic Gulf (Mediterranean Sea) to the south. Minor hydrological basins develop on the two peninsulas (Mani and Vion) at the southern extensions of the bounding mountains of the area. Evrotas valley is predominantly an agricultural region that contains many citrus and olive cultivation fields and pasture land.

### 2.2 Flood hazard assessment methods

Methods of flood hazard estimation have been developed, taking into account the hydrologic basins environmental characteristics, and the particularity of each basin. Most bibliographic reports refer to the methods of Frequency Analysis and Basins Flow Simulation. These methods have been applied for hydrologic systems of the Hellenic region and specifically for the prefecture of Laconia, exporting reliable results. As Basins flow simulation models, we can report the Export Coefficient Models [36] and the Water Quality Models. The Export Coefficient Models usually calculate the loss of material in annual scale, taking into consideration the type of surface (soil, bedrock, cultivations etc), slope and mean annual precipitation. The Universal Soil Loss Equation and the Stream Power Analysis Equation can be mentioned as Export Coefficient Models, where the erosion is calculated in small scale, with the use of simple equations without taking into consideration the spatial parameter. The Water Quality Models have been developed in order to simulate processes in environments without extreme phenomena such as flash floods, debris flows, etc.

However, these methods lead to numeric results referring to specific locations where calculations are applied, cross-sections along streambeds, or flood zones alongside the streambeds, when combined with geomorphological observations, dating and stratigraphic data regarding river terraces.

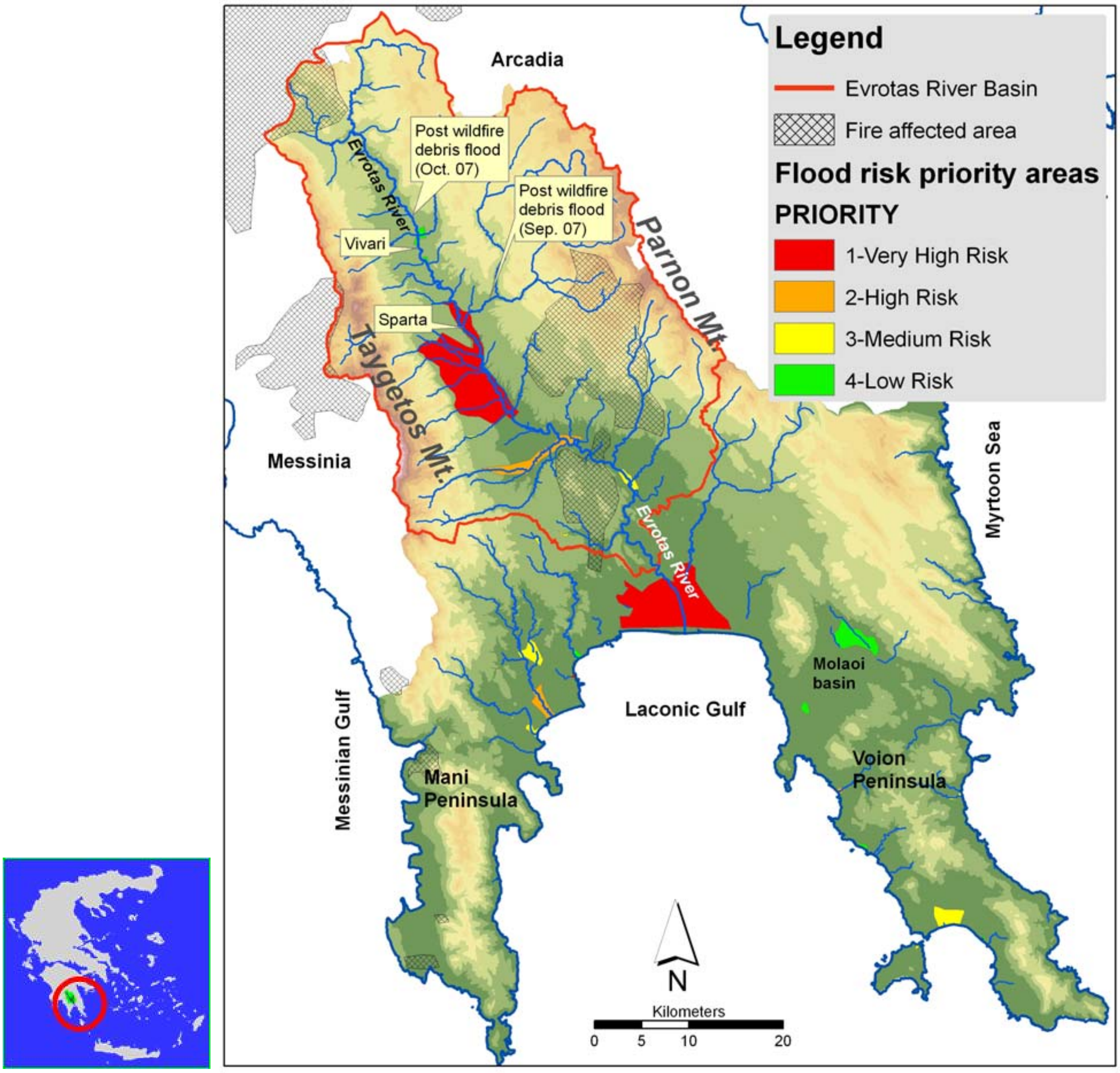


**Fig1**. Flood Risk Map of the study area [37]. The fire affected area of the August 2007 wildfires is marked, as well as debris flood occurrences downstream, soonafter.

### 2.3 Methodology

The present work is attempting to cover the entire area with numeric results for a flood hazard indicator, to match the experience and observations on flooded areas as much as the active (alluvium) deposition record, which reflects flood incidents affecting areas significantly broader than the streambeds alone. The whole methodology is based on some fundamental assumptions concerning the area (so that the method can be applied with reliable results in other areas sharing similar characteristics):

- In tectonically active regions, vertical movements of tectonic blocks separated by fault zones dominate active erosion and deposition areas (and consequently, flood-prone areas) [38]

- Drainage patterns and hydrological basin attributes (area, mean altitude, maximum and minimum altitude, mean slope etc), controlled largely by active tectonics, show a wide range of values, and create contrasts in neighbouring areas.
- Mean annual precipitation is generally proportional to altitude, as a result of the combination of atmosphere circulation with the orographic axis orientation of mountain ranges.
- The long term effects of climate are also fossilized on geomorphology (in erosion and deposition patterns, through landforms, mass transportation and accumulation etc).

Under these assumptions, it is evident that, regardless of the conditions of each extreme or regular weather event, in geological time, tectonically controlled geomorphological attributes define the flood prone areas of such regions, as well as the relative tension for flooding throughout any such area. A calculation based on these attributes shall provide a long term flood hazard indicator, which answers to a critical question for city planning, land use planning, insurance policy etc. Of course, any given precipitation event, differentiates flood hazard because of the specific rainfall spatial distribution, and then one has to overlay and run a dynamic model combining these two type of data, to switch from planning purposes to prediction, operations and emergency response.

The main aim of the study is the final production of the Flood Hazard Map of the study area, at the prefecture of Laconia, which fulfils the assumptions made previously. Flood hazard was estimated using the relief geometric characteristics in the study area and hydrologic basins. The main steps of the followed methodology are:

- calculation of a value indicating the basins and sub-basins energy level, which is determined by
    - precipitation height, which is proportional to the mean elevation of the basin (factor: mean elevation)
    - precipitation volume, which is proportional to mean elevation and basin area (factor: area)
    - pace of transformation of runoff water dynamic energy to kinetic, in relation to the nearest baselevel (basin outlet), which is largely controlled by slope (factor: slope) and maximum and minimum altitude of the basin (factor: total relief)
- interpolation of the calculated values throughout the study area and creation of a basin energy grid
- creation of a slope grid (which is the critical factor for the water velocity reduction, the final accumulation of water in the riverbed and finally, flooding)
- combination of the basin energy grid with the slope grid, for the creation of the final hazard map.

The basin energy grid is based on a calculated parameter, referring to each basin as a single entity, which was attributed in the basin outlets, considered as relative base levels, where relative dynamic energy has been completely transformed to kinetic.

The density and frequency of basins drainage network were also calculated and evaluated, but did not provide significant differentiation of the initial results, at least for this study area. The calculation of these parameters did not result from the simple use of relative equations, but from the elaboration of the Digital Elevation Model (DEM) of the study area and the spatial and quantitative analysis of secondary data, essential factors in the process of calculation.

The production of the Digital Elevation Model was based on the elevation data of topographic maps (1:50000 scale), created by the Hellenic Military Geographic Services (HMGS). With the use of the elevation (DEM) and the relief's simulation of the study area the stream network and drainage basins in vector form (linear and polygonal representation) were produced. The intermediate products of this calculation process were the Flow Accumulation raster, the Flow direction raster, the Stream Order raster, the Drainage Line (vector form) and the Watershed (vector form). The final outputs of this process were the stream system lines (vector) and the polygons of the basins (vector) with all their geometric and geomorphologic values calculated. The results of the described process were displayed on different maps for each basin order group (from 3rd order basins up) allowing the basin analysis in comparison with their geographic placement, as it is shown in the example of the factor of Total Relief for 4th order basins in Fig. 2.

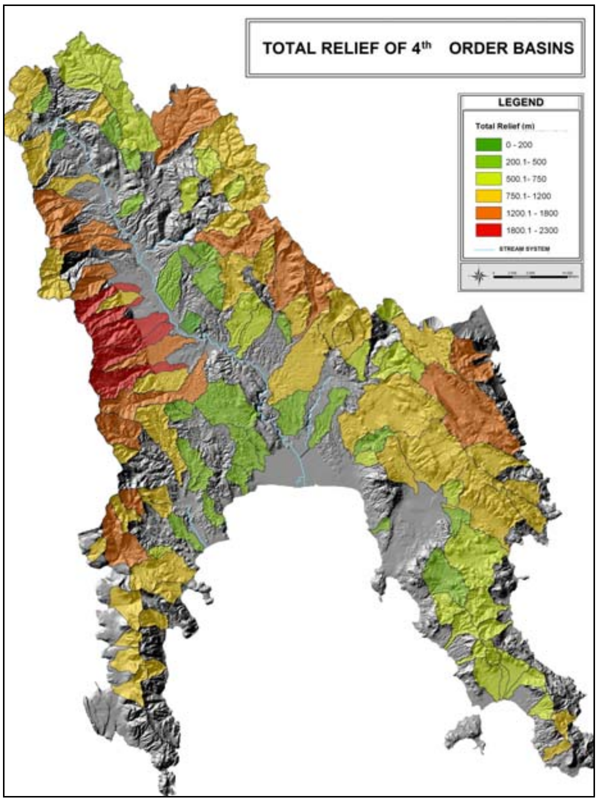


**Fig2.** Total Relief Map of 4th order Basins

Creation of the digital elevation model, as well as all other calculations over the study area were implemented with the use of ArcGIS software (ESRI), and the specialised toolbox ArcHydro. The Arc Hydro tools include operations for terrain processing to derive hydrologically correct terrain models to represent catchments, watersheds, and hydro networks. It also support many types of analysis such as watershed modeling, water network tracing, and flow accumulation calculations.

However, the scale of the study poses restrictions on the terrain elevation data, which derive from contour maps of 20m vertical interval. On smooth relief areas, especially in plains (be there parts of open or closed hydrological systems), detail is reduced, and one cannot rely exclusively upon the automated processes of ArcHydro tools for the creation of sub-basins and drainage network. For that reason, the resulting features of the simulated hydrological model of the area should be corrected largely in areas were they lacked primary data, while there were data about the exact connections between sub-basins and streams. A very characteristic example of possible misuse of the tools, is partly closed dolines along Parnon Mt. or Molaoi basin, where the “Fill Sinks” step of Arc Hydro would “fill” the karstic basin and continue downstream, connecting to the rest of the drainage network, which is an error by all means. In that case, runoff would accumulate in the closed basin, not to create a lake, but to be transformed to infiltration into the carbonates. Thus, the use of ArcHydro and the consequent calculations of basin features were restricted to user-defined sub-basins, determined by the STRAHLER classification, rather than running a model for the whole of the area “in blind”.

## 2.4 Final Flood Hazard Map production

After completion of the individual calculations for basins of all orders, the next phase is the construction of the basin energy grid map, completed in two steps, as described earlier:

- creation of the basin energy factor as an attribute for each basin, and attachment to a unique point theme containing the basin outlets of all orders,
- interpolation based on the basin energy attribute of the point theme for the creation of the basin energy grid map

Rhythm of the energy transformation on the basins outlet is proportional to dynamic energy and inverse proportional to the basins response time (it may be expressed as time of rainwater concentration or as time of flow). Both of the broadly used formulas for flow concentration time, the one of Kirpich ($t_c = 0.01947 \cdot L^{0.77} \cdot S^{-0.385}$), and the one of Giandotti ($t_c = \frac{4\sqrt{A} + 1.5 \cdot L}{0.8\sqrt{\Delta H}}$), take into consideration the mean slope of the basin or the total relief that are inversely proportional to the time of flow concentration In this case the rhythm of energy transformation at the basin outlets (de/dt), is increased at least proportionally to the following values (1) maximum length, (2) mean altitude, (3) mean slope, (4) total relief.

In order to maximize the spatial variation among the basin outlets into the basin energy grid, the calculated factors were put together in a product, acting as contributory factors to the total value. This product certainly does not calculate the rhythm of energy transformation itself at the basin outlet, however it is a well determined quantitative and objective indicator enhancing differences among them. This product can even be used to compare and rank areas from totally non related or non neighbouring regions. The calculating product was applied as a single value to the basins outlet in order to succeed a spatial distribution of this value to the whole study area. Although the spatial distribution of the value within 3rd orders basins close to the watersheds is practically a non-data area (it would have contributed to the map if there were calculations for the outlets of 2nd order, and so on), it depicts very well the spatial differentiation in the interior of all higher order basins (4th, 5th, 6th, etc) and of course in the intermediate area.

As mentioned before, the final step to the construction of the hazard map is the combination of the basin energy grid map with the slope grid map of the area (Fig. 3). The slope map was classified into categories according to slope values, to multiply the basin energy map, with a factor of minimum 1 for slope>10% (no flooding can take place on steeper slopes), to maximum 5 for slope<1%.

## 3. Results – Risk Map production

The results as shown on the final flood hazard map were considered very encouraging for further elaboration of the method. All areas with medium, high or very high flood hazard coincide with the areas of Holocene formations. This means that in these areas, where a continuous deposition action is reported for the last 10000-12000 years, as a result of flooding. For geologists, an exact geological map with explicit detail on Quaternary deposits would be enough to easily depict flood prone areas for a start. The additional advantage of this method compared to purely geological methods however, is the relative ranking of flood hazard among these areas.

Moreover, areas with high or very high flood hazard estimation are verified by the recent flood events reported by the geologists and engineers of Laconia Prefecture with a percentage greater than 60%, as was depicted by overlay of the point shape file of flooding sites over the flood hazard map (no peak discharge data were used). It is important to note that most of the non confirmed cases are locations where human intervention (e.g. roads and infrastructure, construction debris deposition) on the riverbeds, which probably rises the actual percentage of verification to quite higher levels, as far as natural factors are concerned.

A better estimation can be achieved, only if certain conditions are followed. These conditions require the execution of the selected method with great accuracy, as this was described in the previous paragraphs, but also to make calculations for the areas of the 2nd and 1st order basins, which were not included in this study. Finally, it should be pointed out that although this application was not accurate enough, it was proved particularly rapid as methodology and reliable enough for the available time and the application scale.

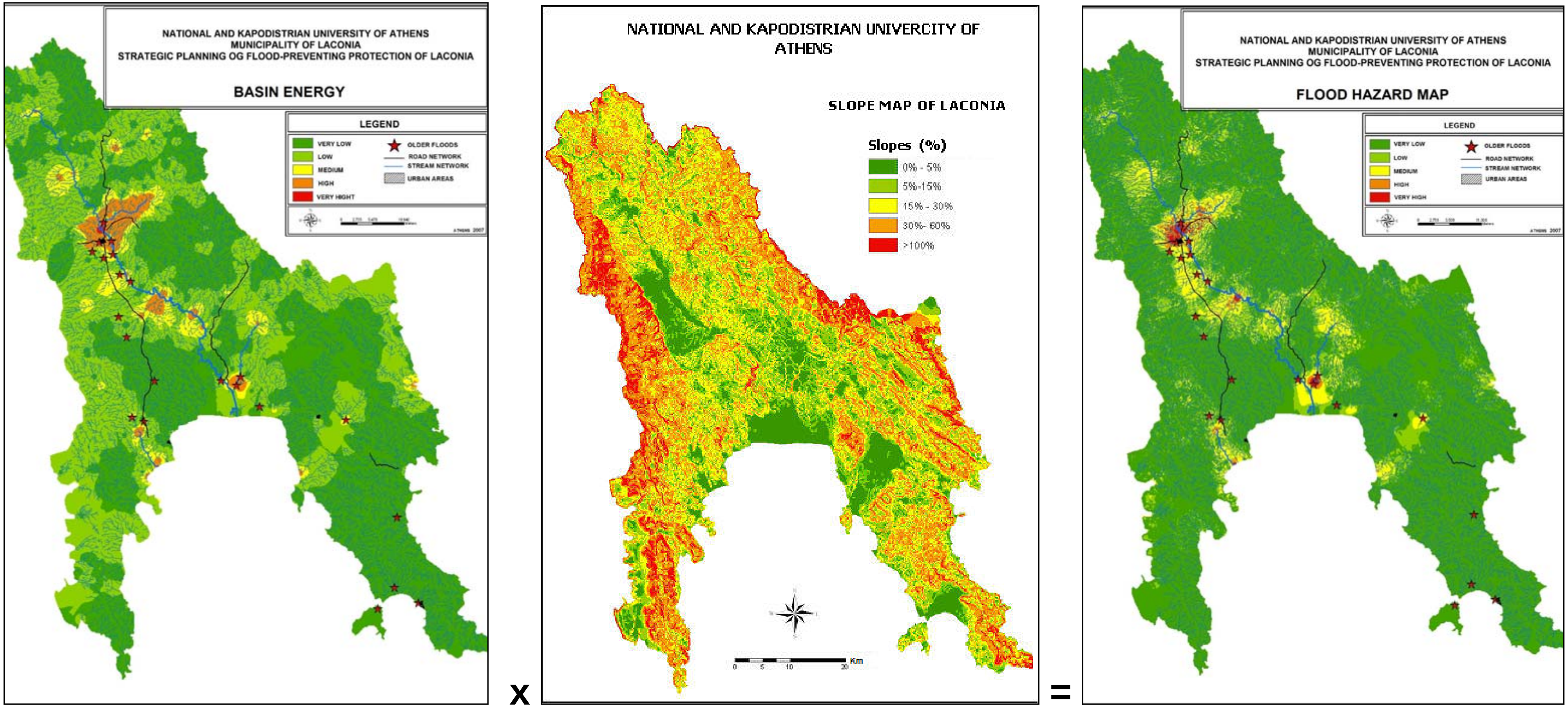


**Fig. 3**. Combination of Basin Energy Map with Slope map leads to the final Flood Hazard Map.

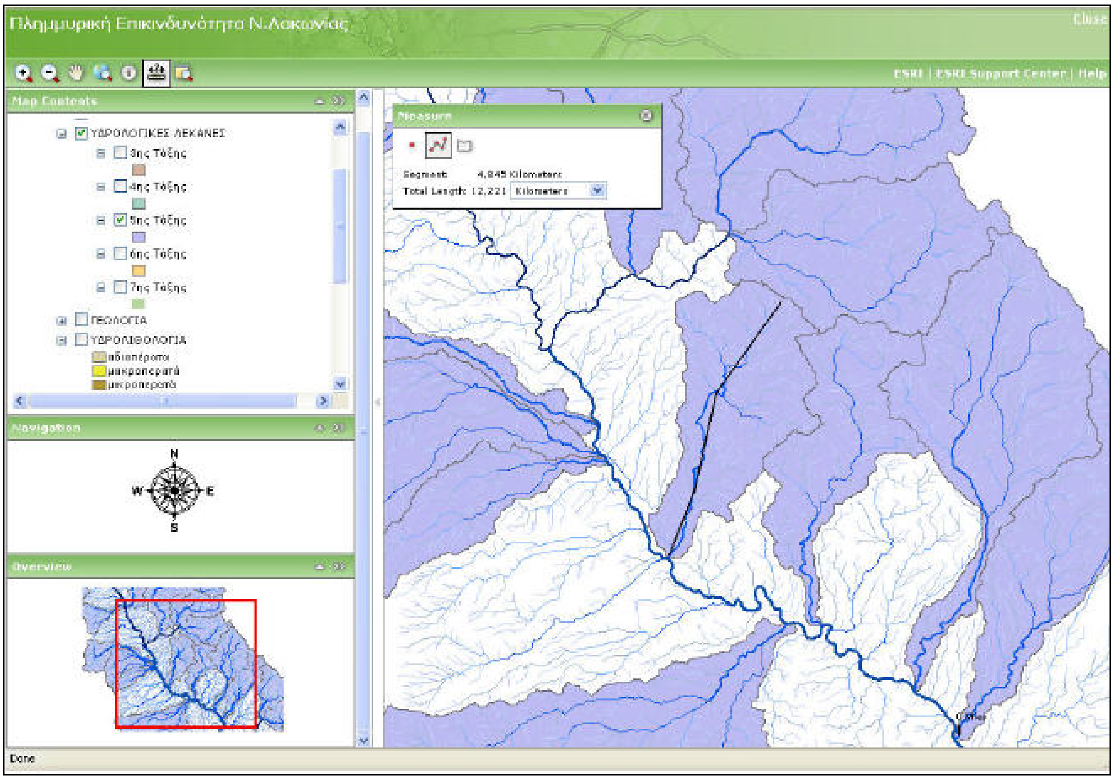
The recorded flood events of recent years (red stars) located within yellow, orange and red areas of the flood hazard map were considered positive results verifying the used methodology.

Moreover, it has to be noted that the results were also verified by the debris flood phenomena following the wildfire of 2007 (depicted in Fif.1), which were included in the aftermath of an extreme disaster, at locations where no previous serious events had been recorded before, but in areas indicated as medium or high flood hazard.

The map of Fig. 1 integrates post wildfire observations about debris flow events following storms over the fire affected areas, soon after the 2007 wildfire, with a form of risk map conducted by the research team in collaboration with the scientists and administrators of Laconia Prefecture.

While Hazard maps depict the hazard potential and probability of occurrence in an area, Risk maps generally depict the form, the stakes and the vulnerability of human presence in a hazardous area, as potential severity of impact in combination with the probability or tension of the specific type of hazard to occur in the area. This relation is usually represented in the symbolic formula “(Risk)=(Hazard)x(Vulnerability)”, but reality is far more complicated than this. In order for this risk map to be created, the research team consulted with the authorities so that areas of human activity (towns and settlements, industrial zones, cultivated areas etc) are delimited and put in order of order of importance, according to their standards (land value, population density, lifelines, etc). In this way, a polygon theme with rated areas of importance was created, and risk was calculated by multiplication of flood hazard to a factor defined by importance attributed to each area. The results presented in the final map show areas where both hazard and vulnerability are high, when no values were given to the intermediate areas, once even if flood hazard was considered high, no vulnerability or value was present. Thus, areas of management priority were defined, so that measures would be taken within and in the basins upstream [37, 38].

The results of this study were published via a Web GIS application with the intention to develop a useful decision support tool. The Web GIS application was developed with the use of the ArcGIS Server platform, and gives to users the desired information via a user friendly framework with all the available tools and data for a flood hazard assessment. The application is accessible from a web browser via an internet connection without requiring any additional installation, giving the opportunity to analyse dynamically (online) the available datasets regarding the flood hazards.



Segment: 4,849 Kilometers
Total Length: 12,221 Kilometers

**Fig4**. Web GIS Applications Screen. Dynamic tool that measures the length of the basins.

## 4. Conclusions

In Laconia, as much as in many other regions of Greece and other countries, there are no time series of runoff measurements, daily precipitation or rainfall intensity data makes it impossible to use any calculation based on such data for reliable frequency estimations about floods and intensities of such phenomena. This method overcomes this obstacle, using the present picture of the long term record of the dynamic interaction of endogenous (such as tectonics) and exogenous forces (weather, climate, erosion) on the earth‘s surface, that is, the geomorphology.

It has to be pointed out that, such complicated and massive calculations over terrain models had been beyond scientific imagination throughout the past of earth sciences, but today they form powerful and low cost tools for difficult as much as critical tasks, such as flood hazard and risk assessment. In fact, the whole methodology presented herewith is based on topographic maps alone (geological maps are supplementary so that the results are cross checked). The only factor restricting the accuracy of the results is the accuracy of the initial topographic maps. As a first step approach to any area where the basic prerequisites of the method (about tectonic activity, precipitation etc) are met, one could hardly find a faster and more economic way to provide results for flood hazard mapping. In fact, the methodology was initially developed to respond to a specific request by the local authorities, after severe floods in Laconia by the end of 2005 and the beginning of 2006. As far as the combination of speed and low cost vs accuracy is concerned, the method met the requirements [39], although it was recognised that a lot of improvement can be made, and the research team has been working since and is ready to present the new results and the evolution steps of the method hereafter, also in Laconia [40] and other regions [41] and other scales.

On the other hand, the development of a web based application reveals that a GIS application with a simple GUI can be used from the non – GIS specialists and that the stakeholders can interact and collaborate more effectively with each other and scientists or consultants. Also, the publication of the flood hazard maps via the internet enhances the public awareness and active participation to the decision making process. Apart from that, it is a cost effective application in comparison to the traditional stand alone desktop applications, once it can be accessed with the use only of a web browser.

Ultimately, the potential of the tool in terms of the additional data interaction with the static flood hazard maps provides the capability to the experts to reassess the flood hazard introducing real time or near real time rainfall data when available and involving the spatial distribution of rainfall to provide dynamic hazard and risk maps, r even run scenarios based on hypothetical rainfall events. This is in fact one of the next steps in the process of upgrade of the methodology by the research team.

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