Spatial Analysis in European Wildland-Urban Interface Environments Using GIS

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Abstract

Wildland-urban interface (WUI) in the European environment and more specifically in the Mediterranean area is a very complex spatial context with many interrelated social, natural resource and wildfire issues. Geographic Information Systems (GIS) can be a useful tool for WUI management, through their capability of handling in an integrated environment multi source and multi resolution spatial data. In the work here presented, some of the GIS analyses performed in WUI areas in the framework of WARM Project are described. The applications in two different scenarios, a temperate one located in the North-western part of Italy and a typically Mediterranean one located in Greece, are demonstrated. The aim of this work is to propose some spatial analysis methods for the study and understanding of European Wildland-Urban Interface environments and their relation to wildfires risk and behaviour. Using GIS to locate and describe relevant WUI areas features enables the further understanding of the magnitude and geographic distribution of the WUI issue within a specific area, enhancing management decision-making processes. The methodology proposed in this paper, resulting to the creation of specific, comprehensive thematic maps can be easily applied in other WUI areas as well, since it takes advantage of the powerful capabilities of GIS tools which are widely used nowadays.

Introduction and objectives

Wildland-urban interface (WUI) environments can be described as composite systems where various structures (most notably private homes) and other human constructions meet or are intermingled with forest, wildland and other vegetation fuels. These composite systems are since the last decades more and more threatened by forest fires, thus creating a new, worrying phenomenon: the wildland-urban interface fire (Pyne *et al*. 1996). These kinds of fires and their related issues are nowadays the real challenge for wildfire researchers and managers.

The WUI in the European environment and more specifically in the Mediterranean area, is therefore a very complex spatial context with many interrelated social, natural resource and wildfire issues (Vélez, 2000).

Information generated through Geographic Information Systems (GIS) analysis is more and more becoming crucial for land-use planning and policymaking in areas of this structural complexity. GIS technology is widely recognized to be essential for natural resources management activities, especially in those areas, like wildland-urban interface ones, where landscapes are experiencing rapid changes (Greenberg and Bradley, 1997).
GIS can provide useful tools for WUI management, through their capability of handling in an integrated environment multi-source and multi-resolution spatial data (Burrough and McDonnel, 1998).
For example, fire management activities specifically oriented to the protection of WUI environments require a definition of WUI boundaries within a certain zone in order to enhance future zoning, control of residential development, fuel management and planning. Spatial data (e.g. digital maps, orthophotos, very high resolution satellite images) processed with a GIS platform and its spatial analysis capabilities, allow to perform preliminary analysis to support this task.
Spatial analysis can be defined as “a set of methods whose results change when the locations of the objects being analysed change” (Longley *et al*., 2001). According to the same authors these methods can be summarized in the following items: Queries and reasoning, Measurements, Transformations, Descriptive summaries, Optimization techniques, Hypothesis testing.

In the work here presented, some of the GIS analysis carried out in WUI areas within the framework of WARM Project are described. The applications are done in two different scenarios, a temperate one located in the North-western part of Italy and a typically Mediterranean one located in Greece, are demonstrated.
The aim of this contribution is to propose some of the spatial analysis methods tested in GIS environment, for the study and understanding of European Wildland-Urban Interface environments and their relation to wildfires risk and behaviour, providing useful elements to guide planning and fire fighting activities.
The analysis were done using ARC-GIS 8.3 by ESRI, applying both vector and raster based functions and analysis such as map overlay, neighbourhood, buffer, surface and hydrologic analysis.
In the next paragraph a brief description of the basic data layers used is given. Next the main features of the two study areas will be outlined and the spatial analysis performed in each one of them will be described.

Spatial data and basic GIS data layer

The first step of our work has been mapping of all relevant basic and derived variables to generate data layers useful for future analysis.
The nature of the phenomenon under consideration requires the analysis to be typically performed at local scale; therefore the basic data layers were built from large-scale maps (i.e. 1:10.000 to 1:25.000). The sources of spatial data were quite heterogeneous: very-high resolution satellite images (Ikonos), aerial photos and orthophotos, conventional maps (in many cases already provided in digital format), field work.
The geographical data considered were those typically needed to characterize the fire environment (e.g. topography, vegetation) and those related to urban development (e.g. houses, roads). Both raster and vector data structures were used and the data layers finally built were the following:

Raster layers: DEM (Digital Elevation Model); slope; aspect
Vector layers: land cover and vegetation (polygons); fuel models/types (polygons); road network (lines); houses (polygons); defence resources location (points).

Italian study case

Description of the study area

The Italian study area is in Piemonte Region located 15 Km North-West from Turin (Fig. 1). The area consists of 5 municipalities with a total extension of about 90 Km^2 and a resident population of about 8500 people.
It includes two valleys: Ceronda Valley and Casternone Valley, with a range of altitude that goes from 300 m to about 1600 m a.s.l.. There are a total of 5 small towns (Givoletto, La Cassa, Val della Torre, Vallo Torinese and Varisella), one for each municipality, and many little villages and hamlets.
Forest vegetation cover is mainly composed by mixed broadleaved stands, with a predominance of *Quercus spp*. Some coniferous artificial stands are also present, covering a small percentage of the area.
The highest elevation belt presents mainly grazing land with forests typically concentrated on slopes, while the lower and flatter part presents mainly agriculture and settlements that usually follow the development of the valleys.
The study area is characterized by small urban settlements intermingled with forest and agricultural landscapes, presenting both situations of classical interface and intermix.
There are in fact villages with a more or less well defined boundary towards natural vegetation but also clusters of houses and isolated structures, the latter often completely surrounded by woodland or brushes.
The area is characterized by an increase of population during holidays and weekends periods, and therefore of the presence of many secondary houses.
The peek of the fire season is a winter - early spring, just in agreement with the dry season of Piemonte Region (Bovio and Camia, 1998). Wildfires are mainly concentrated in the period from January to April and they develop mostly under strong wind condition caused by the Phön wind (Bovio and Camia, 1997).
In the years from 1980 to 2001 there have been 129 wildfires, 98 of which involving WUI conditions (Camia *et al*., 2002; Bovio *et al*., 2002).

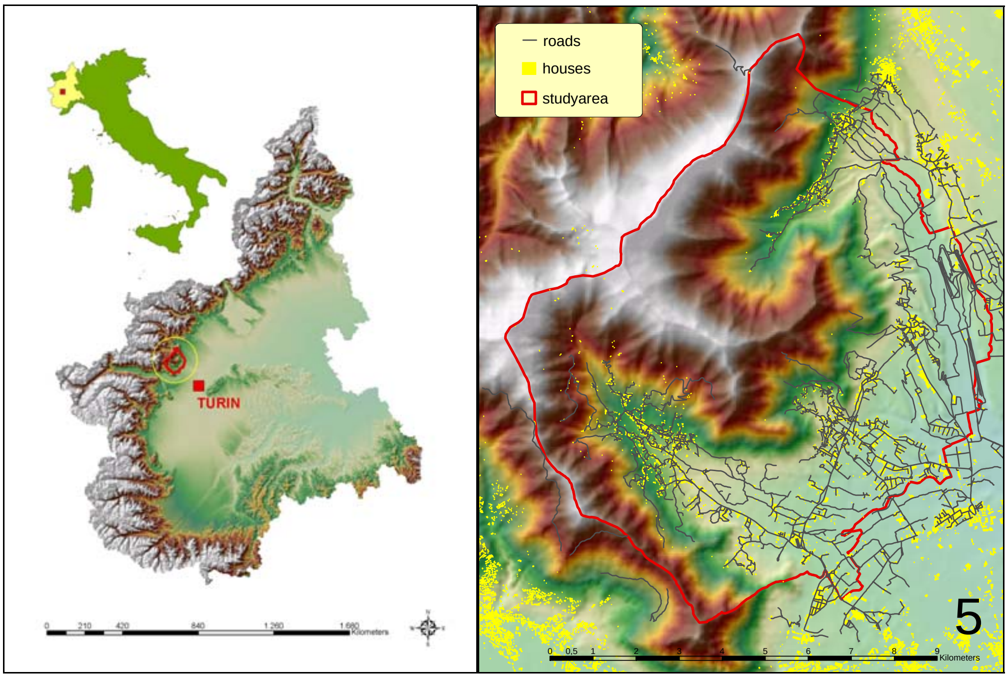

Fig.1 – Location (left) and overview (right) of the Italian study area.

Analysis and results

The analyses performed in the Italian study area were firstly aimed at identifying and typifying settlements, providing a first description of the surrounding environment and of fire suppression preparedness.

As mentioned previously, the study an area is characterized by small urban settlements, presenting both situations of classical interfaces and intermix. Actually an entire set of conditions, ranging from the densely inhabited village with boundaries facing wildland and forests until the isolated houses are represented. Therefore we wanted to identify and classify the different situations according to the degree of urbanization within the wildland area, and therefore the general wildland-urban mixing conditions for the different settlements, being clear the usefulness of such a characterization from a fire management point of view. We approached this task using density analysis techniques to the house layer of the database, and applying thresholds to the derived house density layer and identify in this way settlement boundaries. Settlement types were then characterized by computing the number of houses in each polygon discriminated, performing a spatial join between the settlements and the houses layers. The results are shown in Fig. 2.

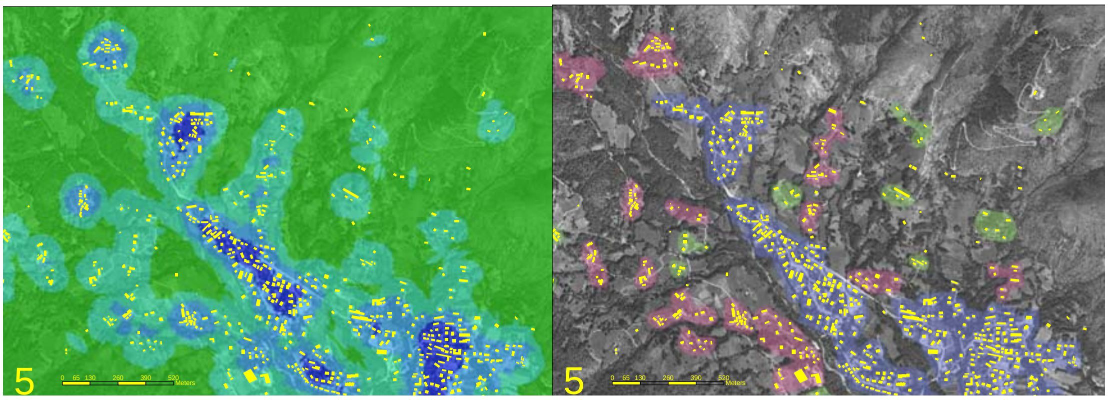

Fig. 2 – House density map (left) and classification of settlement types according to house density and number of houses (right). A grey scale orthophoto map is shown in the background.

A total number of 177 settlements were identified in the study area, classified into three classes (Tab. 1).

Tab. 1 – Settlements of the Italian study area

Settlement type	# settlements in the study area	Average # houses per settlement
A	61	3,7
B	91	12,8
C	25	91,0

To characterize the environment surrounding each settlement, a buffer of 250 m was built and overlaid over the DEM, slope and fuel types data layers (Fig. 3).

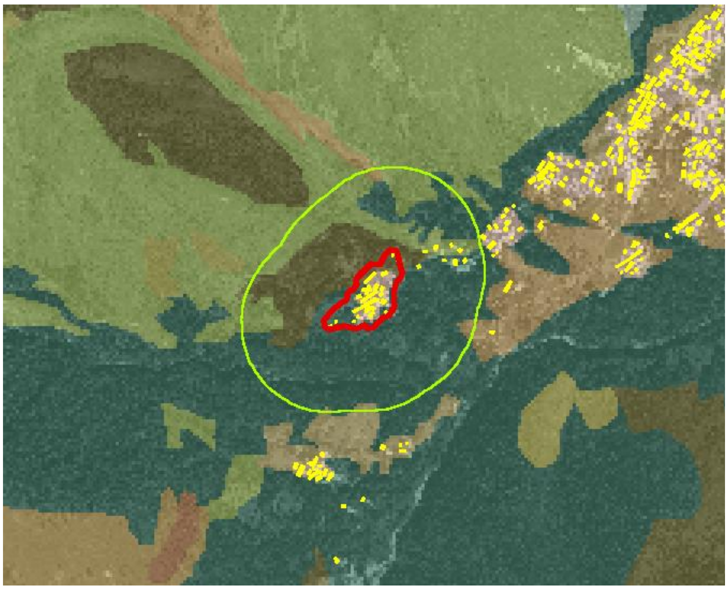

Fig. 3 - Buffer of 250 m around a settlement, overlaid on the fuel type map.

From the overlay results, elevation and slope statistics of the settlements surroundings (buffer of 250 m) were computed. In addition the fractions of the areas covered by the different fuel types were calculated. The results were summarized by settlement type; some of the summary statistics that describe the surrounding environment of each settlement type are presented in Tab. 2 and Tab. 3. Note that fuel types have been grouped by the dominant component of the fuel complexes (herbs, shrubs or trees).

Tab. 2 – Topographic features of buffer area summarized per settlement type.

Settlement type	Average elevation	Minimum slope	Maximum slope	Average Slope
A	509	6,5%	39,7%	19,3%
B	453	4,3%	36,3%	15,3%
C	418	1,1%	41,6%	12,3%

Tab. 3 – Area covered by fuel types in the buffer of 250 m surrounding the settlements

Settlement type	Herbs	Shrubs	Trees	Urban or bare soil
A	79%	13%	4%	4%
B	80%	9%	4%	7%
C	69%	19%	5%	7%

The presence of specific fuel types, as well as the topographic arrangement of the area, provides useful indications about the fire hazard and risk conditions around the settlements, but also about the possibility and strategies for fire fighting resources. In addition to such key features, from a fire suppression point of view, it is important to know the accessibility of the settlements to be protected, as well as the relative location of fighting resources (fire stations) and water supplies.

Although a road density map such as the one shown in Fig. 4 can provide useful information on the accessibility of the sites, much more informative is the map derived from the network analysis that allows to classify each settlement according to the time needed to reach it from the nearest fire station (Fig. 5) or the time from the nearest water supply (Fig. 6).

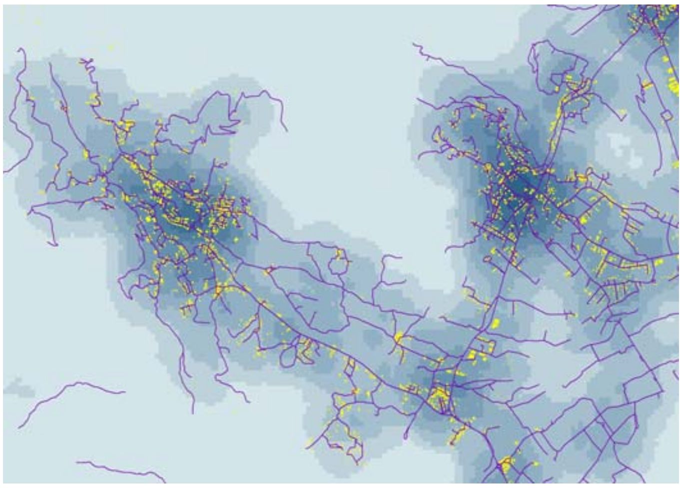

Fig. 4 – Road density map of a subset of the Italian study area.

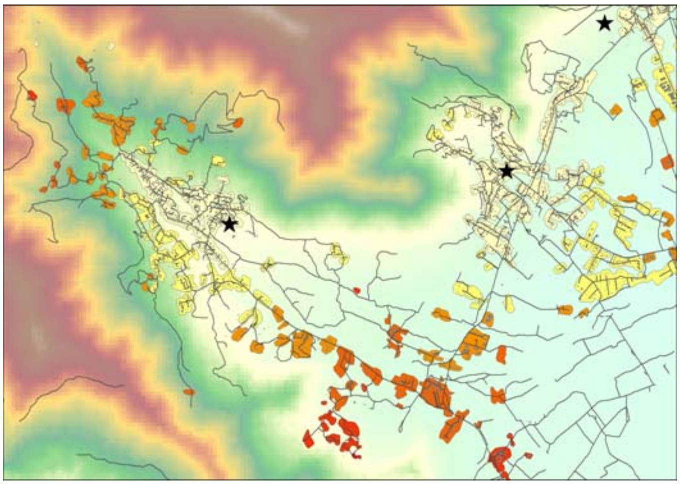

Fig. 5 – Distance of the settlements from the nearest Fire Station (dark stars). Background: DEM

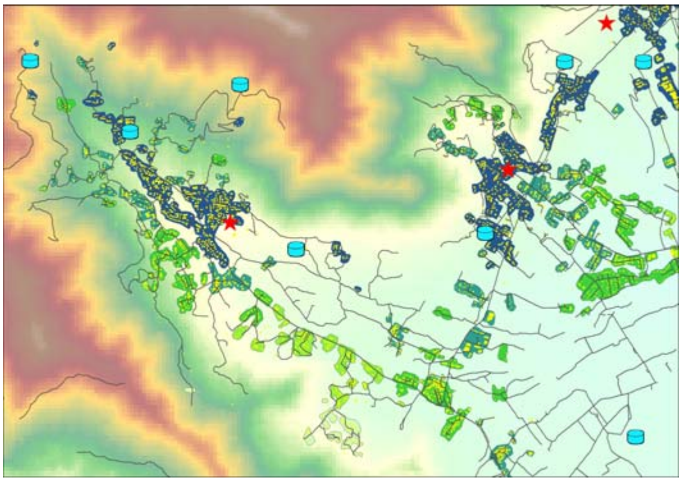

Fig. 6 – Distance of the settlements from the nearest water supply. Background: DEM

Greek study case

Description of the study area

The Greek study area is Penteli Mountain, located at the northern-east part of Athens city. (Fig.7). The total extension of the area is about 100 Km^2, with a range of altitude from sea level to about 1100 m. There are several settlements in the area (N.Makri, Rafina, Drafi, Pallini and other smaller settlements) and separate groups of illegal houses which do not belong to the above settlements.
Forest vegetation cover is mainly composed by *Pinus halepensis* stand with an understory composed mainly by broadleaved evergreen shrubs. Agriculture is present in lower levels as well.
A large number of fires occur in the area historically but the average burned forested areas per year increased significantly during the last 30 years. Intense urbanization process started after 1971. (Varela at al. 1999)

Close this chapter

The study area is characterized nowadays by settlements intermingled with forest and agricultural landscapes, presenting both situations of classical interface and intermix.
Thus, there are settlements with a more or less well defined boundary towards natural vegetation but also clusters of houses, usually illegal ones, often completely surrounded by pine forest.
The area is characterised by the presence of primary and secondary residences and the population increases significantly during weekends and holidays, especially during the summer which is also the fire season for this area.

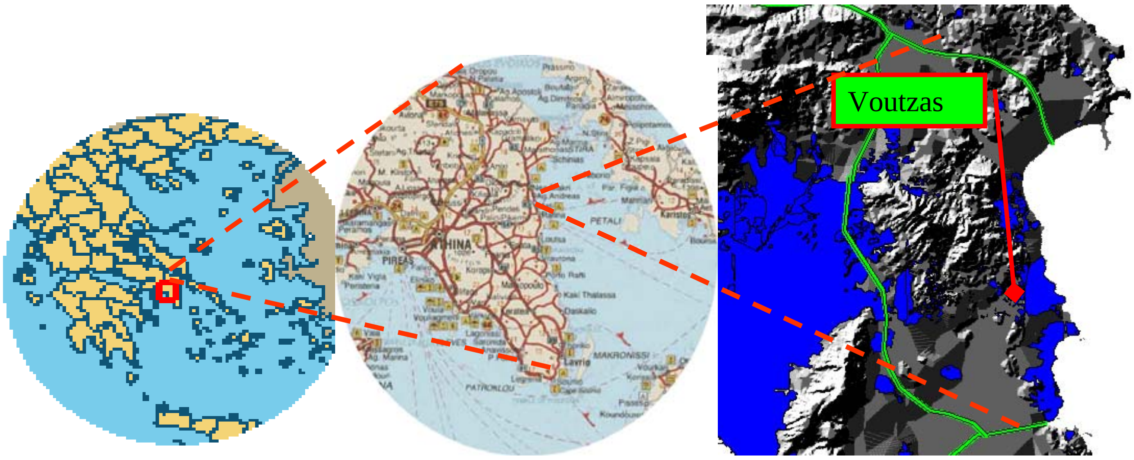

Fig.7 – Location and overview of the Greek study area.

Analysis and results

A two level analysis has been performed in the Greek study area:

- the regional level analysis, aiming at providing a methodology for a systematic definition of the forest fire related characteristics of Penteli WUI environment.
- The settlement level analysis, aiming at the definition of the WUI features within the settlement and the study of the rate of defence and protection of the settlement against fire.

The objective of the first analysis performed at the regional level was the creation of "area accessibility" maps.
Road network was used and analysed with raster-based neighbourhood techniques, for the creation of two accessibility maps, presenting the density of all the types roads and the density of the main roads respectively. More particularly, the 'road density" maps, express the length of road network for each point on the map within a radius of 1000m and are considered as a quantification of the accessibility level of ground mobile means.

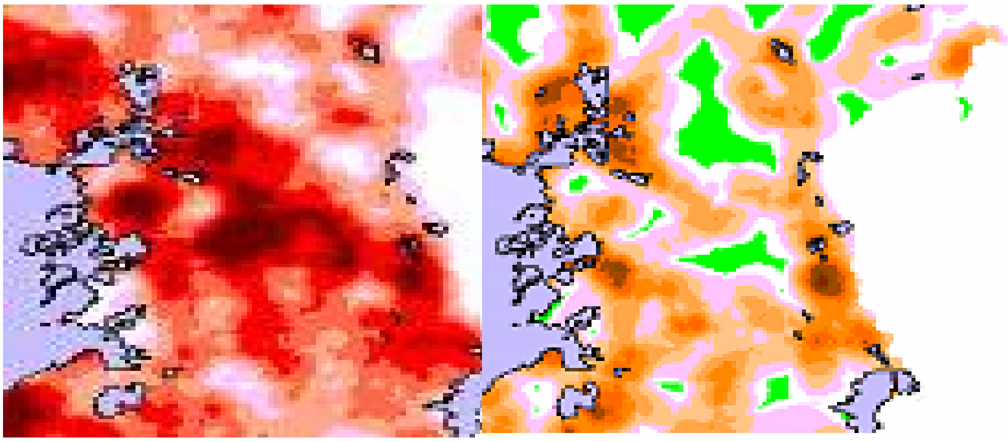

Fig.8 – Regional level analysis: Area accessibility maps, all road network (left),main road network (right)

Another analysis which is useful at the regional level both for fire prevention and fire suppression purposes, takes advantage of the buffer and geographical data-base query techniques of the GIS, for the creation of synthetic maps presenting peri-urban zones around settlements and fire prevention and suppression infrastructure which have been sought and highlighted within this zone.
For the synthetic map which is presented below, the digital terrain (DTM) has been used as the background map and the settlement polygons have been used for buffering and creation of a 2000m peri-urban zone. Road network and water reserve points were the thematic layers queried by the GIS, for the highlighting of the fire related elements within the peri-urban zones. Apart from this particular map, a variety of other synthetic maps can be created, by using various background and fire infrastructure related thematic layers.

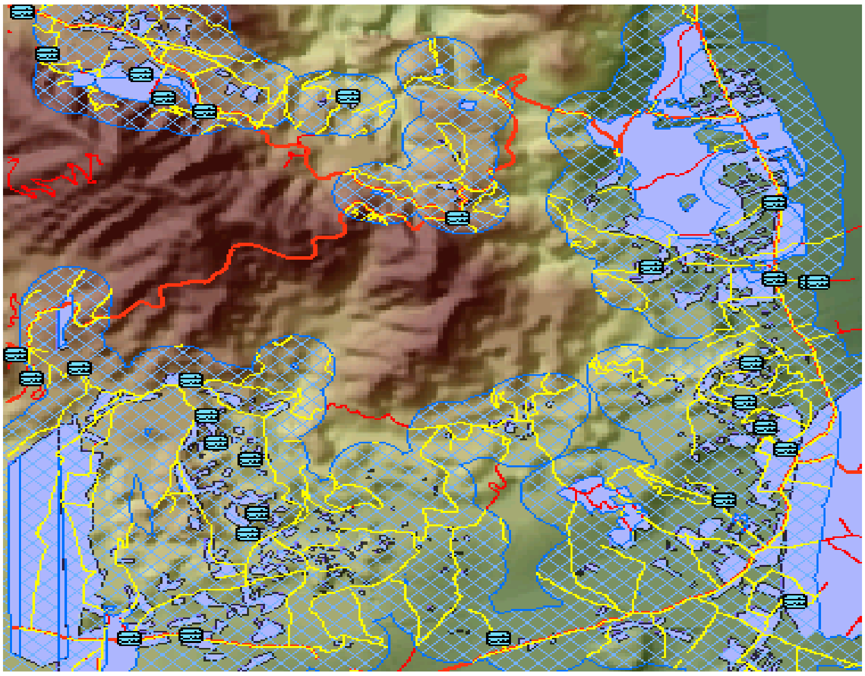

Fig.9 – Regional level analysis: Definition of peri-urban zones and infrastructure within them

For the analyses performed at the settlement level, large scale and detailed geographical information were used. Three basic thematic layers have been used for these analyses: an accurate DTM, the road network (width, type) within the settlement and the polygons of the individual buildings and houses within the settlement.

The first analysis at this level concerned the creation of a comprehensive map showing the urbanization level within the settlement, in other words, the human intervention level in the pre-existing forest area for the creation of the particular WUI zone. Proximity GIS techniques have been applied on the road network and the individual houses layers, for the creation of a composite map showing the density of human structures within the settlement, expressed as the area (m^2) covered by these structures within a 10000m^2 (1 ha) unit area.

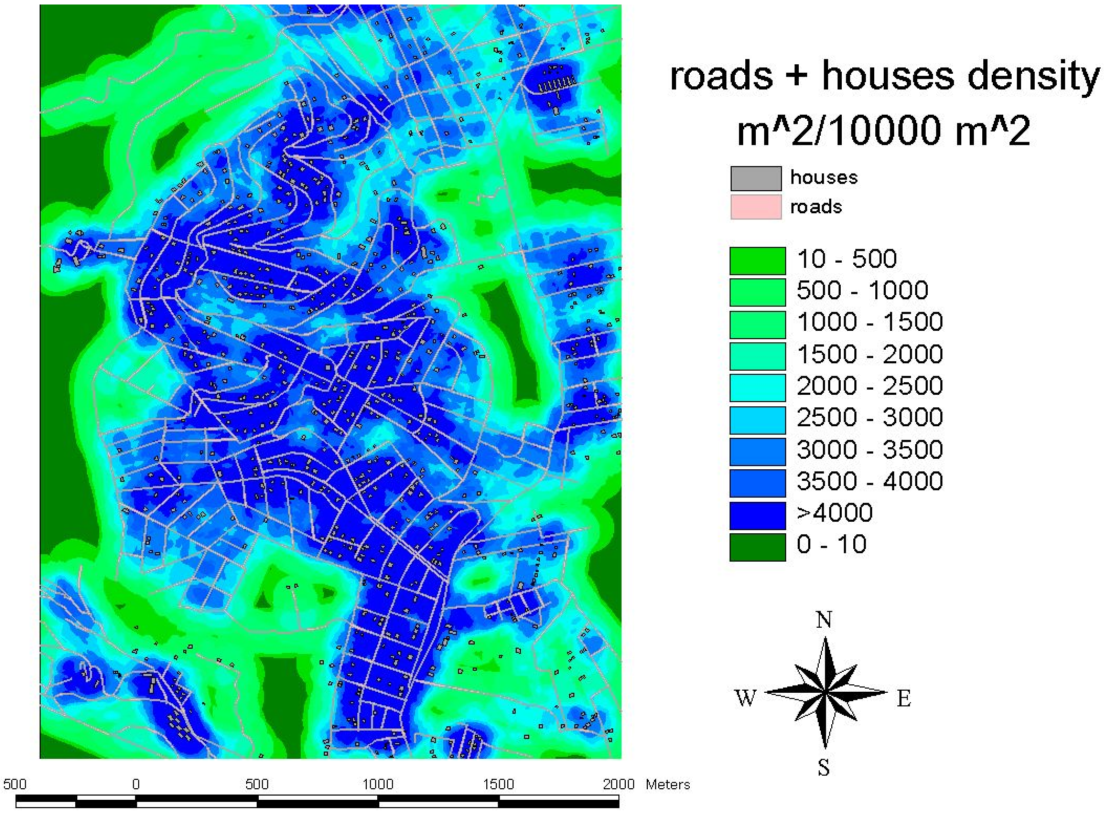

Fig.10 – Settlement level analysis: Urbanization level composite map

Another analysis performed at the settlement level aimed at the study of erosion danger in the WUI zone and the effects of fire presence to it.
The DTM of the area has been used as the basic material for the application of hydrologic GIS functions. Water flow amount and pattern has been studied for two scenarios, namely, for a “non-burned area” scenario and a “burned area” scenario.
The two different scenarios were expressed as two different soil infiltration levels during the GIS processing. The resulting maps which are shown below, present the water flow estimation for the two scenarios respectively. Water infiltration into the soil rate in the burned area, is considered as half of the initial one occurring in non-burned areas, because of the hydrophobic layer which is developed on the soil surface after a

forest fire. Houses and other buildings, as well as roads, are considered as areas where no infiltration into the soil occurs.
According to the derived maps, a larger amount of water is absorbed in the "burned area", which forms larger streams both in length and volume.
As potential water-flow amount and strength is a good indicator of erosion potentiality, it can be concluded that erosion danger is greater in the WUI areas which have been recently burned. The locations where the greatest water flow problems occur are indicated on the derived maps. Thus, these maps can be a valuable source of information for the definition of sensitive locations within the settlement and eventually for the protection of the area against severe erosion and flood danger.

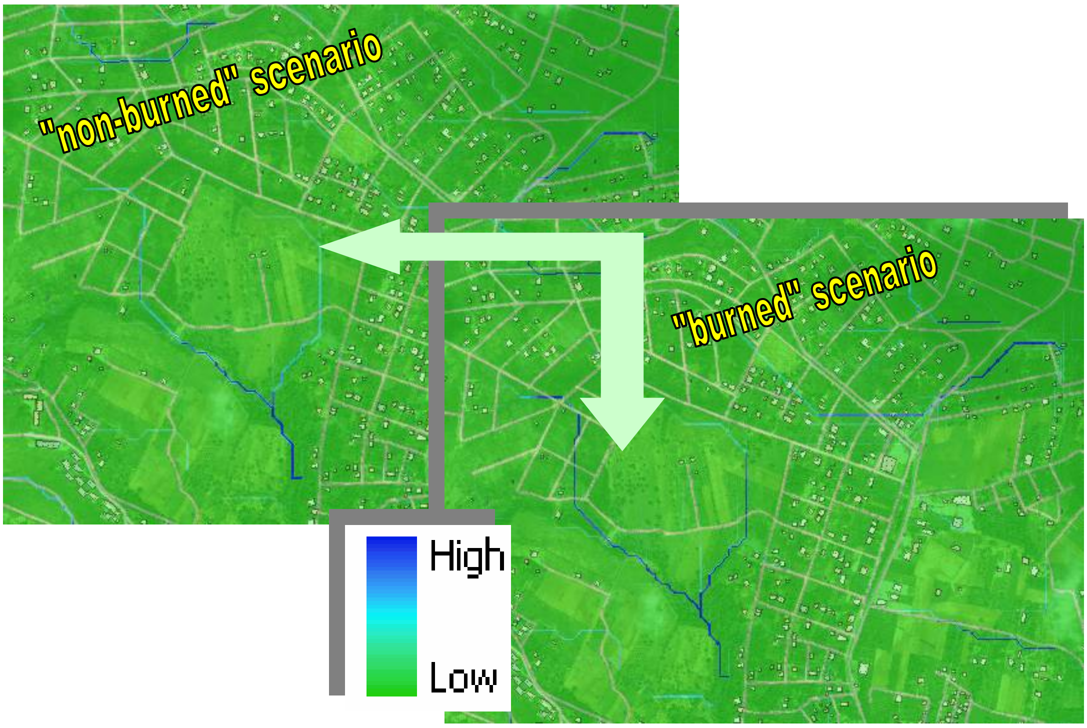

Fig.11 – Regional level analysis: Definition of peri-urban zones and infrastructure within them

Conclusions
Some examples of the application domain of different GIS functions have been shown.
Spatial analysis can be usefully applied to European WUI environments provided that sound data layers are available. Modern tools and techniques for the acquisition of geographical data, such as combination of very high satellite imagery and GIS editing tools can be used for the effective creation and update of digital data layers which can be further analysed by the GIS.
Fire prevention, fire suppression and decision making process can be supported by the use of a number of WUI dedicated, synthetic, digital maps, which are created as a result of various spatial analyses application. Thus, the opportunity is provided to the fire managers to define the WUI zone and study in a comprehensive way the spatial relationships among WUI elements and in turn their relation to the fire behaviour, effects and management.

References

Bovio, G. and A. Camia. 1997. Fire danger rating and land features in Winter-Spring seasons of Northwestern Italy. Report of Minerve Project, EC-DGXII**.** 19 p.

Bovio G. and A. Camia. 1998. Operational Scenarios of Forest Fires in Italy. In Proc. 3rd Int. Conf. on Forest Fire Research, November 16-20, 1998, Coimbra, Portugal. Domingos Xavier Viegas, Univ. of Coimbra, Portugal.

Bovio G., A.Camia and R. Marzano. 2002. Incendi boschivi in interfaccia urbano-foresta: metodi di indagine a scale regionale e locale. Linea Ecologica, 2: 34-41.

Burrough P.A. and R. A. McDonnell. 1998. Principles of Geographical Information Systems. Spatial Information Systems and Geostatistics. Oxford University Press. 333 p.

Camia A., R. Marzano and G. Bovio. 2002. Preliminary analysis of wildland-urban interface fire prone areas in Italy. In Proc. 4th Int. Conf. on Forest Fire Research, November 18-23, 2002, Coimbra, Portugal. Domingos Xavier Viegas, Univ. of Coimbra, Portugal.

Greenberg, J. D. and G. A. Bradley. 1997. Analyzing the urban-wildland interface with GIS: two case studies. J. of Forestry 95(10):18–22.

Longley, P. A., M. F. Goodchild, D. J. Maguire and D.W. Rhind. 2001. Geographic Information Systems and Science. John Wiley and Sons. 454 p.

Pyne, S. J., P. L. Andrews and R. D. Laven. 1996. Introduction to Wildland Fire (Second Edition). John Wiley and Sons. 769 p.

Varela V., Eftichidis G., Maroudi E. and Arianoutsou M.,1999. Land - use changes in an area heavily affected by fire: the case of mt. Penteli. In the Proceedings of DELFI International Symposium on Forest Fires: Needs and Innovations.

Vélez Munoz, R. (Ed.). 2000. La defensa contra incendios forestales. Fundamentos y experiencias. McGraw Hill.