POST-FIRE HAZARD AND RISK ASSESSMENT IN FIRE-AFFECTED AREAS WITH GIS AND SATELLITE IMAGERY: THE CASE OF 2015 LACONIA FOREST FIRE (SOUTHEASTERN PELOPONNESE, GREECE)

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Abstract

On July 17, 2015 a forest fire that broke out in the southern part of Epidavros Limira peninsula (Laconia, southeastern Peloponnese), expanded rapidly due to strong winds blowing in the area and raged out of control for two days, inducing substantial damage to agriculture, livestock farming, buildings and infrastructure and causing one fatality. Innovative GIS-based methods were developed and implemented for the first time in a fire-affected area in Greece for mapping the post-fire erosion, flood and landslide hazards and risks. Geomorphological, geological, tectonic, hydrological, meteorological and land-use data along with a WorldView-2 satellite image and post-fire field observations were evaluated and used. A newly developed method was applied for assessing the erosion hazard. Analytic Hierarchy Process and Weighted Linear Combination methods were used for assessing the post-fire landslide susceptibility. The HEC-RAS model was used for hydraulic simulation and assessment of flood risk under post-fire conditions. Post-fire erosion, flood and landslide hazard and risk maps were constructed for the affected area delineating locations with very low, low, moderate, high or very high hazard and risk of erosion, flood and landslide respectively. The developed methodology is a useful post-fire hazard and risk assessment tool and can be applied by state authorities to assess the geo-environmental impact of fire disasters in areas with similar environmental conditions.

Introduction

On July 17, 2015 a forest fire that broke out in the southern part of Epidavros Limira peninsula (Laconia, southeastern Peloponnese) (Fig. 1) expanded rapidly due to strong winds blowing in the area and raged out of control for two days, inducing damage to agriculture, livestock farming, buildings and infrastructure and causing one fatality. This forest fire is one of the largest in Greece in recent years. The Voies Municipal Unit of the Monemvasia Municipality (Laconia Prefecture) was most affected with Neapolis town and Mesochori, Faraklo, Lachi and Agios Nikolaos villages (Fig. 1) suffering considerable damage. Based on the fire damage assessment performed by the Monemvasia Municipality, the fire-affected area has size of about 60 km^2, 25 km^2 of forest and 35 km^2 of cultivation land were burned in an area extending from the eastern coastal area of Vatika Bay to the main drainage divide along the central mountainous part of the Epidavros Limira peninsula (Fig. 1). Moreover, 10 houses were totally destroyed and more than 150 were partially affected. 100 farm warehouses were totally destroyed, 120000 olive trees and 600 beehives were burned. Infrastructures including the electricity and water supply networks suffered considerable damage.

Immediately after the fire and during the disaster stage, a field reconnaissance team including a large number of experts in the management of environment, disasters and crises visited the affected area in order to evaluate the impact of the fire on the natural environment and to provide scientific, technical and humanitarian assistance to the local authorities and residents. Previous experience from fire disaster management projects after the 2007 Peloponnese wildfires (Lekkas et al., 2007; Mariolakos et al., 2007) were also positively utilized. Among other activities, the team developed and conducted an applied research program and the respective plan for the integrated management of the geo-environmental impact of the fire and the immediate restoration of the fire-affected area. In this frame, innovative GIS-based methods were developed and implemented for the first time in a fire-affected area in Greece for mapping the post-fire erosion, flood and landslide hazards and risks. Geomorphological, geological, tectonic, hydrological, meteorological and land-use data along with a high-resolution Worldview-2 satellite image and post-fire field observations were evaluated and used in order to perform these methods which are described below.

Methods and Results

The erosion hazard map is a mosaic map (raster) derived from the combination of thematic layers representing the individual contributing factors. The combination can be done as a sum, a product, a weighted sum, a fuzzy overlay, etc. No weighting factors were assigned, so the Map Algebra tool in ArcGIS 10.1 (ESRI, 2012) was selected, and the hazard map was calculated as a product, so that the differences between adjacent areas can be maximized. Five thematic maps were constructed in order to be combined into the erosion hazard map. The process was applied twice, so that erosion hazard would be mapped before and after the fire. For the construction of choropleth maps, the natural breaks optimization (Jenks, 1967) was applied, so that natural grouping of areas would not be hidden by equal interval classification.

(1) Elevation map. Annual precipitation in southern Greece is directly proportional to elevation, so elevation itself is a factor that affects rainfall. The area was divided into three zones of elevation and elevation data were reclassified into three values. (2) Slope map. Three classes of slope angle (%) were discriminated to represent high, moderate and low hazard respectively to high, moderate and low slope values. Again data were reclassified into three values. (3) Erodibility map. Geological formations were grouped into three classes, based on their hydraulic conductivity and internal friction. Lower hydraulic conductivity and internal friction classified a formation as highly erodible. As a result, the phyllites-quartzites formations are considered the most sensitive to erosion, followed by the post-alpine sediments, while the limestone formations are considered

the most durable. Geological formations were attributed three values to reflect their erodibility accordingly. (4) Drainage network influence. Water concentration areas are eroded quicker than areas with just overland flow, so three buffer zones of <10, 10-50 and >50 m were assigned high, moderate and low hazard values respectively. (5) Vegetation Map. Land use and vegetation maps were used to evaluate protection of the soil surface during precipitation. Areas were grouped into six classes: (1) mixed zone of bush and forest, (2) thick bush vegetation, (3) thin bush vegetation, (4) cultivated land, (5) residential, (6) fire affected with no vegetation. Highest hazard values were attributed from 1 to 6 respectively.

The wildfire upgraded erosion hazard throughout the affected area, but it has to be noted that hazard was already high around the settlements except for Neapolis, as applies to the most of SE Peloponnesus (Yassoglou et al., 2002). This is also documented by extensive stone terraces constructed in order to hold slopes throughout the area. Conclusively, erosion hazard is higher in the areas of Mesochori and Faraklo villages, and in parts of the areas of Lachi and Agios Nikolaos villages (Fig. 1a).

As far as the post-fire flood hazard and risk assessment is concerned, the study used detailed topographic data to developed a 10x10m digital elevation model of the study area and a very high resolution (0.5m) Worldview-2 image to map all elements relevant to the hydraulic processes, including buildings, obstructions to flow, drainage network, land-cover, manning roughness coefficients, as well as bridges and culverts. Electronic rangefinders with accuracy of 1cm were used to measure dimensions of critical cross sections along drainage routes of the floodplain, which later were used as input in the hydraulic model. HEC-RAS 1-D hydraulic modelling software (Brunner, 1995) was used to simulate water flow across the floodplain. The basic scenario used was the one of 50 years return period, extracted based on the curve number rainfall-runoff methodology (NRCS, 2004).

Simulation results visualized the extent of flood water for the 50 years (or 2% probability) scenario, across the Neapolis floodplain, as it overflowed Xerias torrent, showing that a large part of the coastal area of the town is under risk of flooding (Fig. 1b, 1c). Water flow depth was also visualized with higher values found along the torrent (Fig. 1b), as expected, but also at specific locations along the coast, where infrastructure development and probably old sand dune formations has created a minor rise in elevation that clearly affect drainage locally.

Landslide susceptibility zonation mapping is the quantitative prediction of the spatial distribution of both landslide deposits and slopes. Several qualitative and quantitative techniques and methodologies were proposed for landslide susceptibility mapping in the past decades. In this study, the Analytical Hierarchical Process (AHP) is used along with the Weighted Linear Combination method (WLC) in the frame of the multi-criteria decision analysis. This method has been successfully applied in areas with similar environmental characteristics such as the adjacent Messinia Prefecture (Ladas et al., 2007a, 2007b) located west of the study area in SW Peloponnese. The added value of the application of this methodology in the fire-affected study area is the fact that this is the first time it is applied in a fire-affected area for assessing the post-fire landslide susceptibility.

In this study, the methodology included the development of thematic maps each one representing the spatial distribution and fluctuation of a landslide controlling factor and classes are identified for each factor. Each thematic map is divided into homogeneous areas based on the factor classes. In WLC method the factors classes are standardized to a common numeric range and then combined by means of a weighted average. The selected landslide controlling factors and the respective layers were slope gradient, aspect, curvature, lithology, land use, soil thickness, mean annual rainfall and proximity to roads, rivers and tectonic structures (faults, thrusts and overthrusts). The data used for the preparation of these layers were derived from the topographic sheets of the Hellenic Military Geographical Service (HMGS), the geological map (Gerolymatos, 1999), the neotectonic map (Lekkas et al., 1997) and the soil map (Anestis et al., 1989) of the study area, the meteorological stations covering the fire-affected area. The land use data were obtained from CORINE 2000 (European Environment Agency 2006) and from a Worldview-2 satellite image which was acquired during the post-fire period.

Worldview-2 images are high spatial (1m) and spectral (8 bands) resolution datasets. The main purpose of this work was to use several output image products in order to collect different spectral properties for the earth's surface unities and ideally to separate the burned areas from the non-burned ones. Therefore the digital number (DN) of the raw datasets needed to be converted into objective values through the atmospheric correction procedure. The atmospherically corrected multispectral data were merged with the panchromatic band and a new 8-band dataset of 0.5m spatial resolution was produced. The new image was geometrically corrected and projected in the Greek Geodetic Reference System of 1987 (GGRS '87). During the ortho-rectification procedure a high resolution digital elevation model was used. The latter reached the spatial resolution of 10 meters and was created using contours and height measurements from topographic maps of scale 1:5000. After the basic interpretation, which was briefly described above, the Normalized Differential Vegetation Index (NDVI) was calculated for the area covered by the satellite data, by using band 8 for the Infrared and band 5 for the Red. A new dataset was produced and the burned areas were classified accordingly as the NDVI calculation resulted very low pixel values.

The slope gradient, curvature and aspect maps were obtained directly from the produced DEM in raster format while the others were obtained from vector format digitization that was subsequently transformed in raster format. The assignement of weights and rank values to the raster layers (representing factors) and to the classes of each layer respectively was based on the Analytic Hierarchy Process developed by Saaty (1980) and the factors weights evaluation made by Ladas et al. (2007a, 2007b) for the adjacent Messinia Prefecture. Finally, the weighted raster thematic maps with the assigned ranking values for their classes were multiplied by the corresponding weights and added up to construct a simple map where each cell has a certain post-fire landslide susceptibility index (LSI) value. The higher the LSI value, the higher the landslide susceptibility, whereas lower value means lower landslide susceptibility. This map after reclassification with natural breaks method (Jenks, 1967) in the cumulative frequency histogram of LSI values constitutes the final post-fire landslide susceptibility map of the fire affected area. This final map presents the distribution of the LSI values in five categories of landslide hazard susceptibility: (1) very low (LSI ≤ 31), (2) low (31 < LSI ≤ 40), (3) moderate (40 < LSI ≤ 49), (4) high (49 < LSI ≤ 60) and (5) very high (LSI > 60) (Fig. 1d).

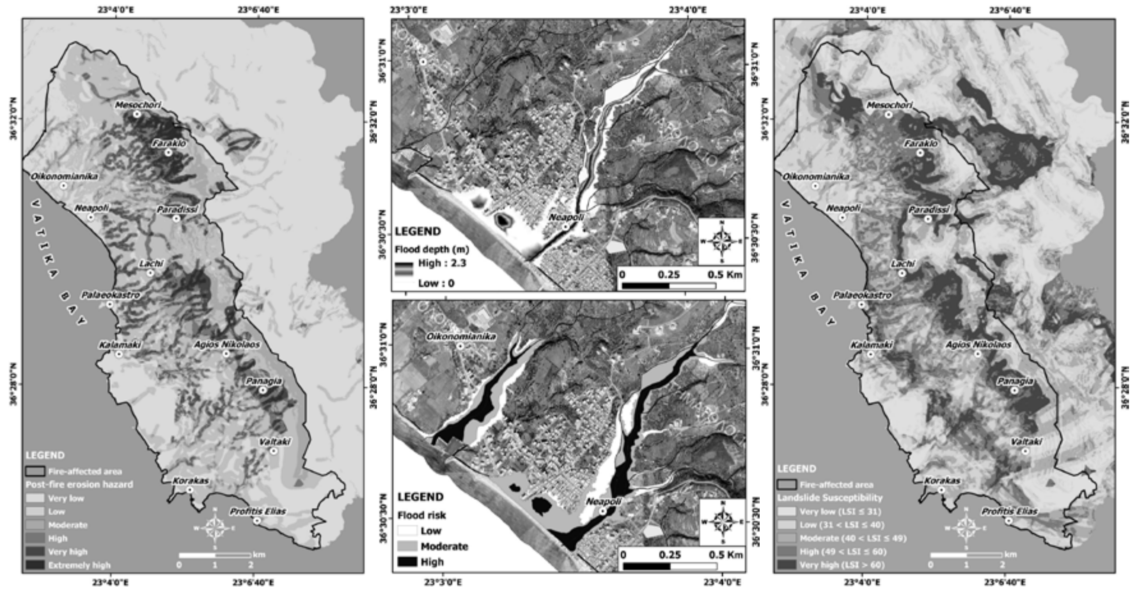

Fig. 1: The post-fire (a) erosion hazard map, (b) flood depth map, (c) flood risk map and (d) LSI map of the fire-affected southern part of Epidavros Limira peninsula.

Conclusions - Discussion

For the first time in a fire-affected area in Greece, innovative GIS-based methods were developed and implemented for mapping the geo-environmental impact of a fire disaster. A newly developed method was implemented for mapping the post-fire erosion hazard. The hydraulic stimulation using the HECRAS model was also applied for the flood hazard and risk assessment. A broadly accepted by the international scientific community method was appropriately modified and applied for the landslide susceptibility assessment. The resulted post-fire erosion and landslide hazard maps illustrate significantly higher post-fire hazards for the mountainous areas of Mesochori, Faraklo, Lachi and Agios Nikolaos villages than that which is shown for Neapolis coastal area. The post-fire flood depth and flood risk maps illustrate that a large part of Neapolis coastal area is under risk of flooding and that the water flow depths for the 50 years scenario present higher values not only along the main torrent of the town but also at specific locations along the coast. The resulted hazard and risks maps were also compared with field observations during our post-fire reconnaissance in the fire-affected area in order to test their performance. This comparison showed satisfactory results.

The developed methodology is a useful post-fire hazard and risk assessment tool and can be applied by state authorities to rapidly assess the geo-environmental impact of fire disasters in areas with similar environmental conditions. This rapid assessment plays a decisive role to the configuration of post-fire emergency measures and the restoration activities in the affected area.

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