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MULTITEMPORAL HAZARD ASSESSMENT IN A HIGH FLASH FLOOD RISK AREA USING RS/GIS TECHNIQUES: THE CASE OF HYMITTOS MT. (ATHENS)

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ABSTRACT

This study concerns the multitemporal flood hazard assessment using remotely sensing data in a GIS context. The study area is located in the western slopes of Hymittos Mt. facing Athens city, which constitute a very critical environment for flash floods combining considerable characteristics like steep slopes, urban expansion, fire events and different land cover types.

Landsat TM images and Landsat ETM+ images were used to demonstrate their usefulness for the temporal change detection, and IRS-1C data have been used for the detection of urban parameters. The conclusion of this study was the monitoring of how the natural and antropogenetic changes, affect the hazard and thereupon the flash flood risk conditions of Hymittos Mt. area.

KEY WORDS: Remote Sensing, GIS, hazard, flash flood, change detection, PCA, NDVI, Hymittos Mt.

1. INTRODUCTION

Rainfalls vary in intensity and duration, and so does the volume of rainwater that runs across the land. Large convective thunderstorms can build up in a matter of hours and quickly set loose the terrifying walls of water known as flash floods, and strike at any time and at any place with little or no warning (Abbott, 1996). In mountainous or flat terrain, distant rain may be channeled into gullies and ravines, turning a quiet streamside campsite or wash into a rampaging torrent in minutes. City streets can become rivers in seconds. Floods are the most visible and destructive hydrologic phenomenon in terms of human and economic loss. As much as 90% of the damage related to natural disasters is caused by floods and associated mud and debris flows (Smith and Ward, 1998). Floods create hazards in several ways:

a) Loss of life, property and services and other social impacts associate with flood flows, b) Scour and deposition in natural channels, c) Erosion of channel banks and beds and deposition of sediments in channels and others areas, d) Possible transport of large quantities of pollutants, e) Landslides and debris flow, f) Alteration of hydrologic characteristics of basins.

Understanding the causes and consequences of floods requires continued research on the geomorphology of the basins as well as monitoring of the correspondent land use changes affecting the hazard.

Cooke and Doornkamp (1990) describe three groups of interrelated factors constitute important flood characteristics: the transient phenomena including the most common cause of flooding which is the heavy precipitation (Barry and Chorley, 1982). The second group is relative to the basin characteristics, drainage network and channel characteristics (geometry, slope etc.) and finally there is a clear relationship between urbanization and changes in the unit hydrograph (Hollis, 1979). According to Alexander (1993) the flooding events in urban areas increase and become more destructive mainly because of:

a) The forcedly constraint of the streambeds at the urbanized areas due to uncontrolled urbanization, b) The barring of the streambeds either by buildings or by debris, especially where failed technical constructions have been made, c) The forest fires and the loss of trees, in general, taking place inside the watersheds around an urban area, d) The decrease of the infiltration along with the increase of surfacial run off as a result of the urbanization, e) The failure in the constructed flood technical works that are not compatible with the environment and in general with the geodynamic settings that take place around the particular area.

Earth observation data are still not in use for the support of the response in a flood event (real-time provision of the data. They could contribute to study and asses the flood risk in an large area as well as to record the flooded zones using multitemporal images (Mc Ginnis and Rango, 1975, Ochi et al. 1991, Biggin and Blyth,

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1996, Sharma et al., 1996, Brakenridge et al. 1998, Parcharidis et al., 2000).

The objectives of this paper are to define the morphological properties of the basins and compute the changes over them using satellite data in a GIS context. Furthermore will be examined the affection of these changes to the hazard variation of them. The relative change in land use over time will be compiled by using satellite data and the morphological and hydrological characteristics will be automatically computed using as base the DEM.

2. GEOLOGICAL-LANDUSE AND METEOROLOGICAL SETTING OF THE STUDY AREA

The Hymittos Mt is located just east of Athens city. The highest point is about 1030 meters and the general direction of N-S. Regarding the lithostratigraphic units Marinos and Petrascheck (1956) and Katsikatsos (1977) suggest the existence of two main geotectonic units (the autochthonous and the allochthonous nappe). Mariolakos and Papanikolaou (1973) revised partially the Lepsius's (1893) lithostratigraphic structure. Lekkas and Lozios (2000) recognized the following units:

a) The lowermost unit, of Vari-Kirou unit represented by a mica- and calc schist formation passing to a sequence of dolomitic and impure marble to a massive dolomite, b) The "Hymittos unit" consisting from the lower to the upper by whitish and bluish marble, schists with marble intercalations, alternates of schists, marble and impure marble, c) The upper most unit of "Lavrio-Athens".

The expansion of Athens city building up shell during the last three decades, contributes to the sprawl building of the slopes facing the basin and this expansion in synergy with the fires produce a high-risk environment for flash flows during extreme weather conditions.

The last 15 years a high number of fires have affected the study area. A total of 16 fire events of different spatial extension and distribution (fig. 1) have occurred (Source: Data base of Institute of Forest Research).

Athens is one of the driest areas of eastern continental Greece. It is characterized by a uniform amount of precipitations during the year, with high intensity which leads to the loss of big quantities of water, through the surface runoff.

The meteorological conditions in Athens according to National Observatory Institute of Athens for the period 1931 to 1992 are the following: The mean high precipitation yearly is about 393 mm, while the minimum and maximum precipitation high yearly varies from 370 to 1100 mm. The most intensive rainfalls, with intensity 3,6 mm/day, happen during the period from September to January and particularly during November. During November take place rainfalls with average value intensity of 6,7 mm/rainday. Oppositely, for the rest of the months the intensity is less than 3,6 mm/rainday.

3. DATA USED - PREPROCESSING

-Digital Elevation Model

The starting point for this study has been the DEM of the area under consideration. In order to create the DEM, the elevation data have been extracted from the 1:50000 scale topographic maps published by the Hellenic Army Geographical Service. The elevation data has been captured by digitizing the contour lines with an equidistance of 10-20 meters in the plain and 40 meters in the highland. Additionally, surface-specific points elevations, including high and low points, have been digitized in order to improve the final digital product. The gridding interpolation method was applied in order to generate the DEM. Also an adaptive smoothing algorithm has been used allowing the local slope-dependent errors in order to be associate with the finite difference representation. Furthermore, an adaptive surface roughness penalty minimizes the profile curvature.

The obtained resolution of the DEM was 25m/pixel. In order to verify its fidelity, the digital elevation model has been again plotted in a 1:50000 scale contour map, by interpolating the elevation values and overlapping them onto the original topographic map, showing thus a very good correspondence of the contour lines.

-Multispectral and high resolution Satellite data

Two Landsat multispectral image segments (free of clouds) have been used covering the study area with the following characteristics:

i. Landsat TM 7 spectral bands, dated 26-7-84
ii. Landsat ETM 7 spectral bands, dated 6-8-99
iii. A high-resolution panchromatic subscene of the Indian Satellite IRS-1C, dated 10-10-99 with less than 10% of cloud cover.

-Preprocessing-Registration

First the panchromatic image of IRS-1C was geometrically corrected utilizing 68 control points well distributed with a few points scattered over the study area. The projection system that has been used in order to georeference the image was the EGSA'87 and then the nearest neighbor method for resampling a spatial resolution of 5 m/pixel has assigned. Next step was the geometric correction and co-registration of the two Landsat images using as reference source data the already georeferenced IRS-1C panchromatic image, with an error of less than one pixel and spatial resolution of 25 m/pixel for both Landsat images.

-Data Processing and analysis

The basins of the area were calculated automatically from the DEM using as minimum area the 2500 cells, in a second step some of the selected basins have been unified. The properties for each of the basins have been stored in an attribute table with the following fields containing the numeric information (table 1):

a) id, the identification number for each basin, b) Basin area, that is the area draining to catchment's outlet, with runoff volume significance, c) Perimeter of the basin, d) Flow length distance, e) Mean stream flow length, determining, with the previous parameter, the stream sinuosity, f) Mean elevation, the mean basin elevation in meters above the sea level with significance about climate, vegetation, and potential energy, g) Mean slope, with significance about overland water flow velocity, geomorphology etc.

The above parameters and their significance constitute the primary attributes in order to describe the morphometry, catchments position and surface attributes of hillslopes. In total 10 basins have been discriminated on the slope facing Athens city (fig.1). The result has been evaluated by overlapping the boundaries of these basins on the DEM. The result is good and the only negative aspect of the automatic discrimination is the existence of small parts of the DEM that have not been classified in a basin.

Table 1. The data attribute table, containing information regarding the hydrological and morphological characteristics of the recognized basins.

Basin-id	Basin area	Perimeter	Mean flow distance	Mean stream length	Mean elevation	Mean slope (%)
5	13159050	21250	4683	1170	324.14	10.187
8	6651250	20450	7892	5439	425.58	14.367
9	6727500	17950	7398	4938	471.57	16.709
10	5163750	12100	4077	693	345.77	14.468
14	1900000	8800	3617	25	380.09	16.137
16	6753125	17500	6287	2152	310.70	16.330
19	9606250	19450	6054	2539	292.90	14.480
23	5961250	13500	5552	1325	117.95	9.070
25	2260000	14150	5434	2034	217.80	11.098
28	2868750	13800	4930	2051	68.86	7.029

This computation problem probably is due to the limited capability of the system to insert and classify small areas which are less than the predefine numbers of cells. An attribute table accompanies the graphic map of the basins, showing the fields which correspond to the hydrological and morphological information.

4. SATELLITE DATA PROCESSING AND ANALYSIS

The principal components transformation is a redundancy reduction technique that generates a new set of eight variables (components), starting from the original bands, with which to describe multispectral remote sensing data (Richards, 1994). According to the fact that the first component contains more of the variance in the data, the second contains the next major portion of variance etc. Additionally, their principal component axes correspond to uncorrelated data so it could be used as a data transform to enhance areas of local changes in multitemporal multispectral images (Fung and Le Drew, 1987).

From the registered Landsat subscenes the first four bands, of both dates, have been selected, in total 8 bands, from which a new set of eight principal components have been generated. The first component corre-

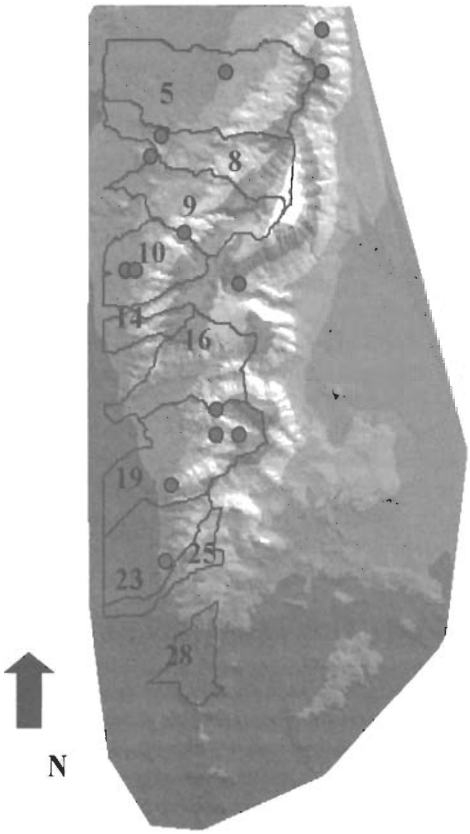


Fig.1. The automatically discriminated basins in the east facing slope of Hymittos Mt. In the image are also recognized the two areas not included in a basin, and with circles the starting point of the fires that affected the area the last 15 years.

sponds to the brightness image (information concerning topography) while the rest of the components contain spectral information related to the surficial changes that took place during the time separation of the two images. The burned areas (old and new) are shown in the PC2, PC3 and PC4 as darker or slightly lighter than the average of the image. The built up areas are well discriminated from the non-built up areas mainly in the PC4 and secondary in the PC2. The revegetation is shown as bright pixels in the PC3 image mainly along streams of Hymittos and the new green-zones in the build-up shell. The last four PC's contains a small amount of information relative to other applications and "noise".

a) A composite image has been created using PC3, PC2 and PC4 components. This shows the burned areas of different times of occurrence as dark gray, urban areas as medium gray and light gray for mixed areas, build-up and vegetated areas (fig. 2a).
b) Using the third and forth bands of both dates Landsat images the NDVI images have been created. By creating a layer stack of the two NDVI images a new change detection image was generated (fig. 2b), in which the dark gray levels represent the deforested areas while medium gray the reforestation during the period 1984-1999, and the light gray the unchanging vegetated land-cover.
c) From the IRS-1C PAN the building blocks, the main streets parallel to the outlet of the basin and the streams crossing the city have been recognized and have digitized on screen (fig. 2c).

5. RESULTS-DISCUSSION

The polygons corresponding to the basins were transferred from ArcView to ERDAS and converted into raster format. In this form have been used as a mask in order to crop the initial images into basin extension images.

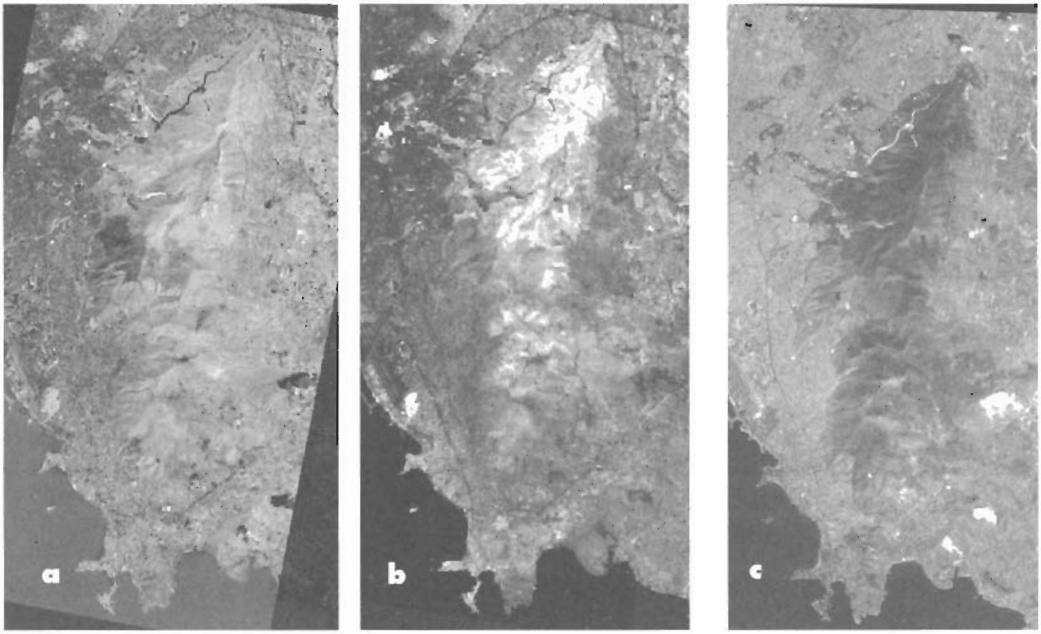


Fig.2. The composite image using PC3, PC2, PC4 in gray scale (a), the NDVI layer stack image using NDVI84 and NDVI99 (b), the IRS-1C Pan image with 5m/pixel of resolution (c).

By incorporating all the above processed data, three characteristic basins have been chosen taking into account the crucial parameters which can affect the flash flow hazard and the related hazard changing:

Basin 5

Basin 5 is located at the northwestern part of Hymittos Mt. close to the Zografou and Papagou districts (fig. 3).

The large size of the basin especially when the rainfall event covers part of it, diminishes the flash flood risk. In addition, the high value of the ratio of Mean flow distance to Mean stream length (showing a relative high sinuosity) and the small value of mean slope, show a low susceptibility in flash flood conditions. Oppositely, the fact that the urban area covers almost the half of the basin, constitute a disadvantage because reduces the infiltration of the rainfall and increases the direct surface runoff. This creates problems especially in the downstream part of the basin where the urban cover is located.

The interpretation of basin 5 shows that the experienced changes were located mainly to the eastern part. The basic changes occurred in the construction of Attica highway and in small expansion of building shell to the eastern part of the city. The natural vegetation cover at the uppermost hills has not changed during the last 15 years. Also, it is obvious that the revegetation occurs mainly along the streams and in some small regions inside the urban area (small parks).

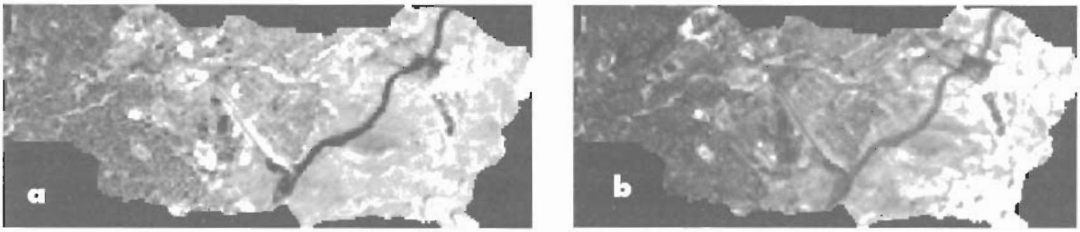
The main streets in the urban area are parallel with the drainage network (figure 3c) contributing to the stormwater runoff. Conversely, Attica highway constructed perpendicular to the drainage flow direction blocking in that way the channels. For this reason flood controls and efficient sewers construction are needed.

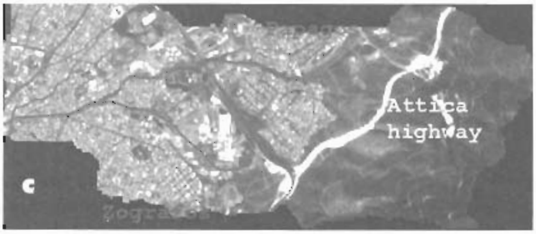
Generally, all the above parameters lead to the conclusion that in basin 5, the last 15 years, hazard has remained stable. Thereupon, is not expected any aggravation to the flash flood events.

Basin 16

Basin 16 is located at the middle part of Hymittos Mt. close to the northern part of Elliniko district (Fig.4).

This basin is characterized as a small size area, with a small value of the ratio of Mean flow distance to Mean stream length (showing a relative low sinuosity) and steep slopes (16,3%). These characteristics indicate a high susceptibility in flash flood events. Another characteristic of the basin is that only a small part of it is covered by the urban "impermeable" area and thus decreases the direct surface runoff. On the contrary, the small size of this basin, the narrow mountain shape and the crucial parameter concerning the pointing of the build-up area





Basin Area 13159050
Perimeter: 21250
Mean Flow distance: 4683
Mean stream flow length: 1170
Mean elevation: 324.14
Mean slope: 10.187

Figure 3. Basin 5. The grayscale composite image using PC3, PC2, PC4 (a), the NDVI layer stack image using NDVI84 and NDVI99 (b), the IRS-1C Pan image (c).

exactly at the outlet of the basin (hence, receiving a big volume of rain water from all the watershed in a very small span) revoke the above advantage.

In this basin, fire events in the last 15 years have led to a very intense deforestation located in the north and northeastern uppermost parts. The building shell expansion appears in very small areas and vegetation regrowth appears vigorous mainly along the streams. Furthermore, the direction of the main streets of the city is parallel with the basin's outlet so the flash flow is with increased velocity.

The above analysis shows that basin 16 has undergone dramatic deforestation changes over the past 15 years. This extensive deforestation and urban expansion will affect soil structure and reduce infiltration rates and water storage, hence, will increase accordingly the runoff volumes and suspended solids loads.

Considering the above parameters an aggravation of flood hazard was estimated. Taking into account this element and the present high susceptibility can conclude that the basin can be classified as a high-risk area for dangerous flash flood events.

Basin 19

Basin 19 is located at the southern part of Hymittos Mt. close at the southern area of Elliniko district.

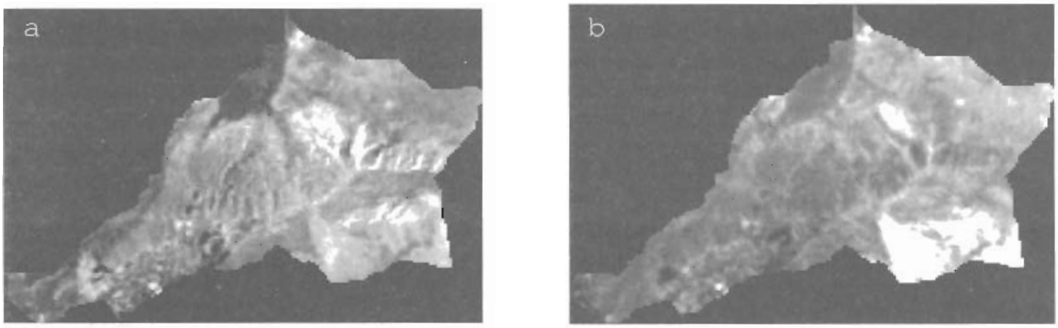
This basin is relatively big with steep slopes and with a small value of the ratio of Mean flow distance to Mean stream length (have very low sinuosity, creating high velocity of rainwater surface runoff).

The major changes pointed in the urban expansion are located mainly to the eastern part of the city (the black zone in figure 5a). Additionally, the revegetation along the main streams was significant.

It is clear that the bigger part of the basin covered by the urban shell, minimizes the infiltration rate. Simultaneously, the main streets do not fit with the flow direction of the streams that drain in the basin. These two parameters increase the surface runoff and change the channel morphology and transmissibility. These components lead to the hazard aggravation during the study period increasing the susceptibility of basin 19 to flash flood events.

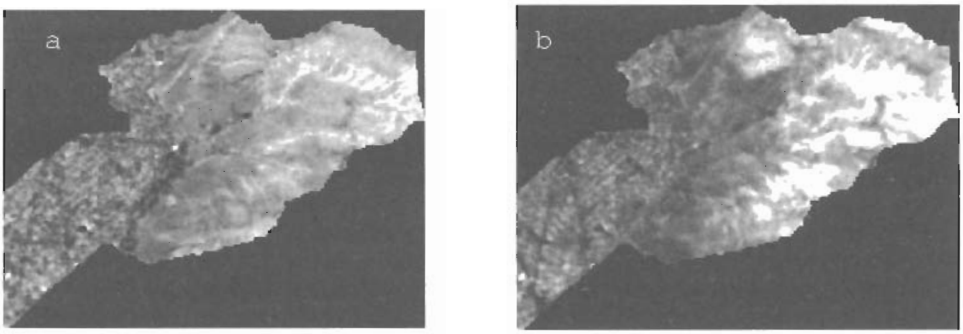
6. CONCLUSIONS

- The combination of remote sensing and GIS techniques is a helpful tool for the detection of land use patterns changes over time in relation to economic, social and environmental factors. Understanding the nature of changes in the environment, in both natural and anthropogenic environment, is an essential knowledge to facilitate proper planning, management and regulation for natural risk management.
- -Satellite data of high spatial and spectral resolution could be used but an additional effort should be done in order to improve the operation ability of this type of data.
- In this application considerable changes in land use were recorded in Hymittos Mt. during the period 1984-1999. According to these changes the flash flood hazard for this period was estimated concluding that there were different levels of aggravation for each basin.



Basin Area: 6753125
Perimeter: 17500
Mean Flow distance: 6287
Mean stream flow length: 2152
Mean elevation: 310.70
Mean slope: 16.330

Figure 4. Basin 16. The grayscale composite image using PC3, PC2, PC4 (a), the NDVI layer stack image using NDVI84 and NDVI99 (b), the IRS-1C Pan image (c).



Basin Area: 9606250
Perimeter: 19450
Mean Flow distance: 6054
Mean stream flow length: 2539
Mean elevation: 292.90
Mean slope: 14.480

Figure 5. Basin 19, The grayscale composite image using PC3, PC2, PC4 (a), the NDVI layer stack image using NDVI84 and NDVI99 (b), the IRS-1C Pan image (c).

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