

THE CONTRIBUTION OF EARTH OBSERVATION TO FLOOD RISK ASSESSMENT IN CYPRUS: THE CASE STUDY OF YIALIAS CATCHMENT AREA IN NICOSIA

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ABSTRACT

The main goal of this study is to highlight the contribution of satellite remote sensing and GIS to the estimation of flood risk in a watershed basin in the area of Nicosia, Cyprus. For this study multispectral satellite remote sensing imagery such as Landsat -5 TM and ASTER was used to record the urbanization activity during the time period from 2000-2010. The results clearly demonstrated an increased rate of urban development in the area. Additionally, the integrated use of Geographical Information Systems (GIS) and Satellite remote sensing imagery contributed to the detail digital mapping of the area's drainage network. Geomorphometric parameters of the basin were calculated and the results were imported in GIS environment in conjunction with the results derived from the ASTER imagery classification processes regarding urban expansion. The final flood risk assessment maps denote the fundamental contribution of satellite remote sensing and GIS to the construction of a friendly user and effective flood risk assessment model.

1 INTRODUCTION

Nowadays floods are considered to be one of the most devastating natural disasters worldwide. A flood can be determined as a mass of water that produces runoff on land that is not normally covered by water (Ward, 1978). Ecosystem and floods are closely related and any changes in the ecosystem, such as urbanization across the catchment's area, may trigger off a sequence of flood occurrence causes (Hadjimitsis, 2010). Moreover, floods frequency is increasing with a steady rate and due to ever increasing human activities on physical floodplains there is a respectively increasing of financial destructive impact of floods. As globally averaged temperatures increase, the potential for severe to extreme weather events increases (Becker et al., 2003). The extreme weather and global warming in recent years has demonstrated the necessity of effective flood risk management models. According to this conception, a considerable shift has been observed from structural defense against floods to a more comprehensive approach including appropriate land use, agricultural and forest practices (Barredo and Engellen, 2010).

This study is accomplished in the framework of SATFLOOD scientific project and presents its preliminary results. The specific project concerns the integrated study of a watershed basin in the island of Cyprus in terms of flood risk assessment. Multi-temporal digital mapping of urban sprawl with the use of means of satellite remote sensing and evaluation of the hydrological and hydraulic potential of Yialias drainage network for future flood inundation are the main goals of the project.

2 METHODOLOGY, STUDY AREA AND DATA

2.1 Methodology

The digital mapping of drainage network and the monitoring of urban sprawl with means of satellite remote sensing contribute to an efficient flood risk assessment. Initially, a Landsat 5-TM image was acquired and preprocessed. The Principal Component Analysis was applied to the image and a high pass filter was applied in the 2nd component of PCA result. The enhanced image was used from the authors for the derivation of the basin's drainage network and the correction of the initial network that had been extracted from the GIS Digital Elevation Model (DEM) automatic procedure.

At a next step multiple geomorphometric parameters of the watershed basin being essential to the study of basin's hydrological regime were estimated. Additionally, different parameters concerning flood risk assessment such as slope, geology and distance from the drainage network were imported and classified in a sophisticated GIS model. As far as it concerns land cover and urban sprawl, three geometrically and atmospherically corrected ASTER images were used to record the urban expansion in the area for the time period of 2000-2010.

All the flood risk parameters were normalised with the application of a fuzzy logic algorithm and the contribution of each parameter to the final model was estimated with the use of Analytical Hierarchy Process (AHP).

The calculation of the Flood Risk Index (FRI) in the form of digital maps for the three different time periods denoted the vitality of land cover parameter to such kind of risk assessment models.

2.2 Study area

Located in the central part of the island of Cyprus the area's study area is about 110 km² in size (Figure 1). Specifically the study area is situated between longitudes 33° 11' 24, 28'' and 33° 26' 31,52'' and latitudes 34°54'36,74'' and 35°2' 52,16''. The island of Cyprus is located in the northeastern most corner of the Mediterranean Sea and, therefore, has a typical eastern Mediterranean climate: the combined temperature-rainfall regime is characterized by cool-to-mild wet winters and warm-to-hot dry summers (Michailides et al, 2009).

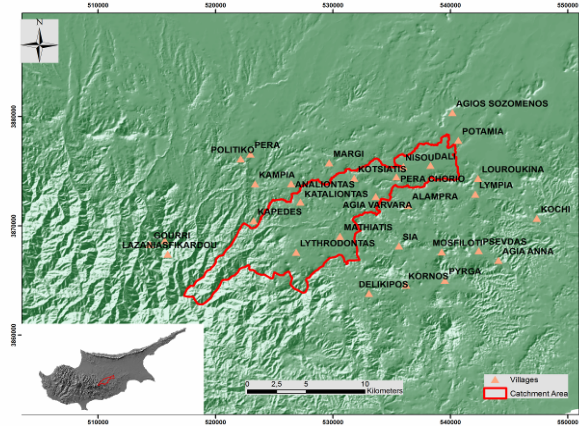


Figure 1. The study area.

For the purposes of the study the following satellite and digital spatial data were incorporated:

- 3 ASTER Images
 - 1 Landsat 5-TM Image
 - A Digital Elevation Model (DEM) of 25m pixel size provided by the Department of Land and Surveys of Cyprus and created with the use of orthorectified stereopairs of airphotos covering the study area.
- The acquired ASTER images had a 5 year time acquisition interval and the first three spectral bands of 15m spatial resolution were used (VNIR and SWIR). The exact acquisition dates of the images were: 12/05/2000, 24/04/2005 and 06/04/2010. Additionally, a 30 m pixel size multispectral (7 bands) Landsat 5-TM image acquired at 25/09/2009 was used.

3 PREPROCESSING AND POST PROCESSING OF REMOTE SENSING DATA

3.1 Preprocessing techniques

Initially geometric corrections were carried out using standard techniques with ground control points and a first order polynomial fit. For this purpose topographical maps were used to track the position of ground control points in conjunction with the digital shoreline of Cyprus extracted from the provided DEM.

At a next step the authors proceeded to the conversion of DN values to radiance values. Concerning ASTER images this task was accomplished through the equation 1:

$$Lrad = (DN-1) * Unit\ Conversion\ Coefficient \quad (1)$$

The radiance values of Landsat image were converted to radiance through the equation 2:

$$Lrad = DN * Grescale + Brescale \quad (2)$$

where *Grescale* and *Brescale* are band specific rescaling factors.

Moreover, for the images of both sensors the at-satellite radiance values were converted to at-satellite reflectance values by using the general equation 3:

$$P_p = \frac{\pi L_\lambda d^2}{ESUN_\lambda \cos \theta_s} \quad (3)$$

Where :

P_p unitless planetary reflectance

L_λ spectral radiance at the sensor's aperture

d^2 earth-sun distance in astronomical units

$ESUN_\lambda$ mean solar exoatmospheric irradiances

θ_s solar zenith angle in degrees

In this study, the darkest pixel atmospheric correction method was applied to every image (Hadjimitsis et al., 2004 a,b).

3.2 Post processing techniques

In order to search the diachronic expansion of urban cover in the watershed basin, classification algorithms such as Maximum Likelihood, Minimum Distance, Mahalanobis Distance and Spectral Angle Mapper were applied to the three ASTER images through the Erdas Imagine v.10 and ENVI v.4.8 image processing software. The time period to be searched was 2000, 2005 and 2010 when considerable construction and urban development had been recorded to the whole island of Cyprus. The training classes that were used for the supervised algorithms were: 1) urban cover, 2) vegetation, 3) bare soil, 4) forest, 5) geologic formation of chalk (Figure 2).

During the supervised classification process the authors had to deal with the problem of similar spectral response of chalk/marls geologic formations and urban constructions that affected the validity of the final results.

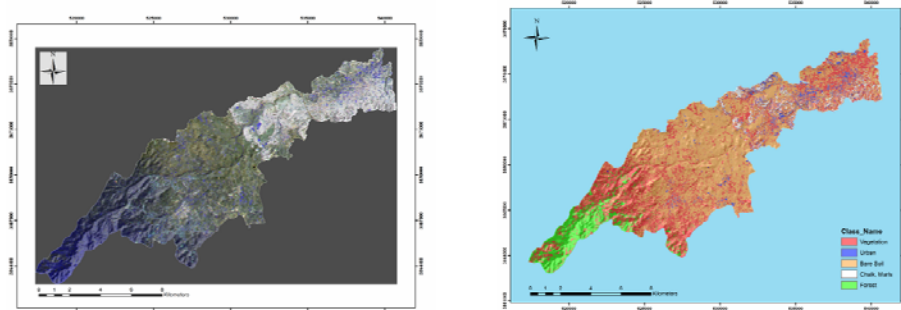


Figure 2. ASTER image (RGB – 1,2,3) of study area acquired at 12/05/2000 (left). Application of ML classification algorithm to ASTER image (right).

At a next step the overall accuracy of each method was computed by using the Kappa coefficient which indicates whether mapping results are significantly better than randomly generated results (Martinez and Toan, 2009). The values of coefficient vary from 0 to 1. The Kappa value of 0.80 for Maximum Likelihood (ML) classification algorithm suggested a good agreement above chance between classified pixels and reference pixels. Regarding ML, at the specific algorithm the statistical probability is computed for each training class to determine the membership of the cells to the class. The classification results (Table 1) concerning urban sprawl denoted a major urban area expansion during the time period of 2000-2010 that ranged from 90 -110%.

Table 1. Statistics of urban expansion during the time period of 2000-2010.

Maximum Likelihood	2000	2005	2010
Urban area (km ²)	4.0359	10.859	19.128

In recent years, the automated determination of drainage basin parameters has been proved to be efficient, time saving and an ideal application of GIS technology (Kouli et al, 2007). However, the satellite remote sensing has been used in many studies as an additional alternative for more detailed mapping of watershed's basin drainage network. Initially, the authors proceeded to the automatic digitization of basin's drainage network through the automatic process of DEM in ArcGIS 9.3 environment. At the same time the ordering of the drainage network was performed according to Strahler's system.

The next step involved the determination of some more water lineaments from the satellite images in order to improve the already created network. According to Kouli et al. (2007) the 2nd principal component of Landsat-ETM satellite image is ideal for correction and updating of the drainage network. Principal Component Analysis involves a mathematical procedure that transforms a number of correlated variables (spectral bands) in a smaller number of uncorrelated variables called principal components (Alexakis et al. 2009). The authors proceeded to a further image enhancement in order to improve the portrayal of the drainage network and facilitate its extraction. Several multiband enhancement techniques were used. Finally, an edge enhancement convolution filter of 3*3 kernel was applied to the 2nd principal component of Landsat image.

The following kernel was used:

$$\begin{array}{ccc} 0 & -1 & 0 \\ -1 & 5 & -1 \\ 0 & -1 & 0 \end{array}$$

As explained by Mather (1987) the application of the specific high pass filter is to subtract the Laplacian of an image from the image itself.

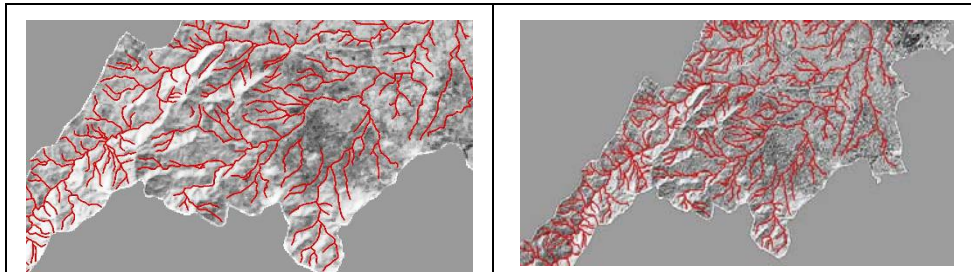


Figure 3. 2nd principal component of Landsat Image and overlay of the automatic generated drainage network (left). Application of edge enhancement filter to the 2nd principal component of Landsat image.

4 GEOMORPHOMETRIC PARAMETER

The basic watershed characteristics (basin area, perimeter, cumulative length of streams and basin length) were calculated in GIS environment. Morphometric parameters such as stream frequency (Fu), drainage density (Dd), texture ratio (T), form factor (Rf), elongation ratio, (Re) and bifurcation ratio (Rb) were evaluated with mathematical equations (Strahler, 1964). Additionally, other morphological parameters such as hypsometric curve and hypsometric intervals were calculated (Table 2).

Table 2. Geomorphometric parameters of Yialias Basin.

Morphometric Parameters	Yialias Basin
Streams Total Number	408
Total Stream Length (km)	287.74
Basin Length, Lb	65.908
Area, A (km^2)	110.432
Stream Frequency, Fu	3.6945
Drainage Density, Dd	2.6055
Texture Ratio, T	3.6433
Form Factor, Rf	0.7754
Elongation Ratio, Re	0.09
Bifurcation Ratio, Rb	4.39

The stream order analysis of the drainage network revealed that is of fifth order. The calculation of Drainage density (Dd) parameter is considered to be crucial for the research of the hydrological regime of the watershed and the impact of geology and hydrolithology to it. The value of 2,605 is considered to be low and indicates rock formation of high permeability, low relief and sparse vegetation. Moreover, the Stream Frequency has also low value, a fact that amplifies the previous conclusion (Figure 4). Concerning elongation Ratio (Re), the value in Yialias River is extremely low and indicates high infiltration of watershed basin and low run off capacity.

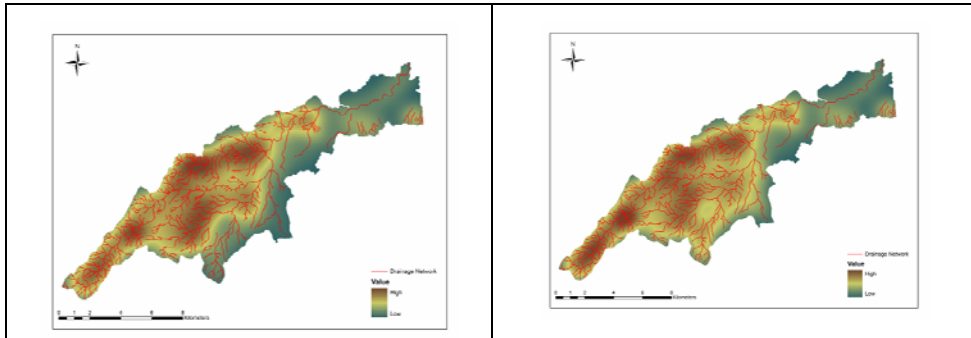


Figure 4. Drainage density maps and drainage network (left). Drainage frequency map and drainage network (right).

The value of Form Factor (R_f) in Yialias basin highlight the potential of the specific watershed for flash floods phenomena. The 0.7754 value is evidence that Yialias has low main flow in longer durations and high side flow in shorter duration (high peak). However, the value of Bifurcation Ratio is considered to be high.

The hypsometric curve is mainly related to the rate of erosion that has occurred in a basin. The hypsometric interval contributes to the estimation of the amount of erosion that has taken place during the past geological time (Bishop et al., 2002). Hypsometric curves are usually interpreted as youthful, mature and old age stage of landscape evolution. The hypsometric interval (HI) represents the area under the hypsometric curve and corresponds the percent of original mass rock remaining in the watershed. Based on the hypsometric curve and the corresponding hypsometric interval the Yialias basin seems to be in a transition stage from the mature stage to old stage ($HI=30,36\%$) of its development according to Strahler (1964). Thus, the drainage network of the basin has started to be broader at the eastern low relief part of the basin and more integrated at the western part of higher relief. Moreover, by using Boolean algebra in GIS environment the normalized raster layers of drainage density and frequency were summed to form the drainage texture raster layer where high values indicate areas of high permeability rocks (Figure 5). After this process, a sigmoidal membership monotonically increasing function based on Fuzzy theory was applied to the final interpolated image to classify the values from 0 to 1 indicating a continuous increase from non membership to complete membership. Fuzzy logic is based on the theory of fuzzy sets where membership is a matter of degree. In this case, the binary membership was replaced by partial membership ranging between 0 and 1 (Ocalir et al, 2010).

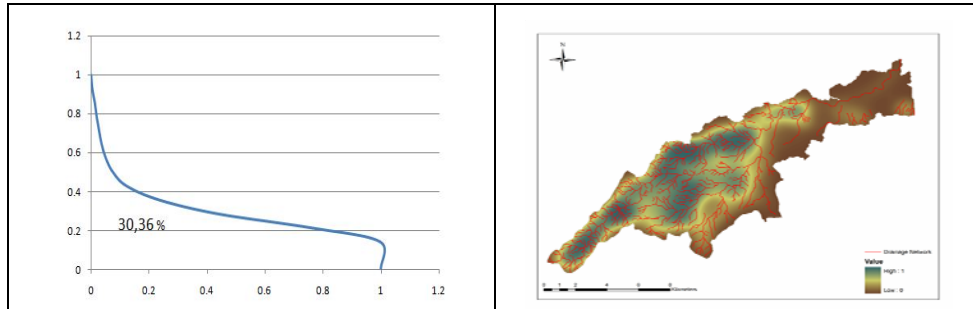


Figure 5. Hypsometric Curve of Yialias basin (left). Drainage texture map (right).

5 MULTICRITERIA ANALYSIS

The multi criteria methodology followed in this paper is a simple one and is generally based on the analysis of some parameters that control water routing when high peak flows exceed the drainage system capacity (Fernandez and Lutz, 2010). In order to evaluate the flood susceptibility of the study area the final model incorporated five different variables in GIS environment: Distance to the channels, slope, geology, drainage texture and land cover.

According to the rate of contribution of each parameter to area's flood vulnerability, ranking values were assigned to each different class of each parameter. At the next step the fuzzy algorithm as in the case of drainage texture was applied to convert all the raster values to final digital layers with values ranging from 0 to 1.

At the end, weight values were assigned to each parameter. The values were extracted with the use of Analytical Hierarchical Process (AHP). In the multicriteria analysis the parameters used to construct the final flood risk assesment model were :

5.1 Slope

Slope is considered to be a crucial parameter to identify the zones that have shown considerable susceptibility to flooding over the years due to low slope gradient. It is well known that the slope of the relief in a watershed is an important factor in determining the water velocity. Thus, on flat areas where pond areas occur, a considerable amount of the surface run off may be retained in temporary storage.

The slope map was prepared in GIS environment using the 25m pixel DEM of the study area and the values were classified to 5 different classes according to Table 3.

5.2 Geology

The geological regime of an area is crucial for the determination of the flood vulnerability of the area. The geological map of Yialias basin was unified to eight major geological formations which were ranked according to their rate of hydro permeability (Table 3).

5.3 Distance to the channels

According to the records of the Department of Water Development of Cyprus the most affected areas during the flood of 27th of October 2009 in Yialias River were those areas

in the vicinity of the main channel as a consequence of water overflow. Thus, all the areas from both sides of the channels were mapped in GIS environment with the use of buffer zones and a rank value was assigned to each zone in relation to their proximity to the drainage network (Table 3).

5.4 Land Cover

Impervious cover such as buildings, roads and generally urban constructions can add substantially to run off procedures in a watershed. 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 land cover regime of the area was searched thoroughly through the use of multi temporal satellite images as it was described in the previous chapters. The different land use classes were ranked (Table 3). Regarding the specific parameter 3 different layers were imported to the final model representing the land cover status at 2000, 2005 and 2010.

Table 3. Rank values for the different parameters.

1	Slope	Ranking
	2<	9
	2-5	6
	5-8	4
	>8	2
2	Geology	Ranking
	Shichsts	9
	Marls, Chalks	8
	Igneous Rocks	7
	Volcanic Rocks	6
	Fanglomerate	5
	Alluvium	4
	Limestones	3
	Sandstones	2
3	Distance to the channels (m)	Ranking
	< 50	9
	50-100	7
	100-200	6
	200-500	5
	500-1000	4
	1000-1700	2
4	Land Cover	Ranking
	Urban	9
	Chalk	7
	Soil	6
	Forest	5
	Vegetation	4

5.5 Application of Analytical Hierarchical Process (AHP)

After the implementation of rank values to each parameter in GIS environment and the classification of the values of GIS raster layers from 0 to 1 through the application of a fuzzy logic algorithm, the AHP method was used to contribute to the extraction of final weights in an objective way. Basically, AHP is a multi-objective, multi-criteria decision making approach that employs a pair-wise comparison procedure to arrive at a scale of preferences among a set of alternatives. Moreover a certain grade is assigned to all the different pairs from 1/9 when the factor is “not important at all” to 9 where the factor is “extremely important. Pairwise judgments are made based on the best information available and the decision maker's knowledge and experience.

Table 4. Application of AHP method.

	Slope	Distance from Channels	Geology	Land Cover	Drainage Texture	Sum	Final Weights
Slope	1	1/3	7	3	5	16.33	0.284
Distance from Channels	3	1	9	5	7	25	0.436
Geology	1/7	1/9	1	1/5	1/3	1.783	0.031
Land Cover	1/3	1/5	5	1	3	9.53	0.166
Drainage Texture	1/5	1/7	3	1/3	1	4.672	0.081
						57.366	

At the final stage all the digital layers were imported in GIS environment and the final flood risk assessment model was implemented for the three different time periods by using three different land cover raster layers. The Flood Risk Index (FRI) was calculated through the equation 4:

$$\text{FRI} = [\text{Slope}] * 0.284 + [\text{Distance from Channels}] * 0.436 + [\text{Geology}] * 0.031 + [\text{Land Cover}] * 0.166 + [\text{Drainage Texture}] * 0.081 \quad (4)$$

At Figure 6 the three different flood risk assessment models are demonstrated for the three different time periods. The Figure 6d indicates the result of the spatial subtraction of the 2000 raster layer from the 2005 layer. With red, yellowish and light blue color the areas where increased values of flood risk have been recorded are presented because of land cover differentiation through the time period of five years.

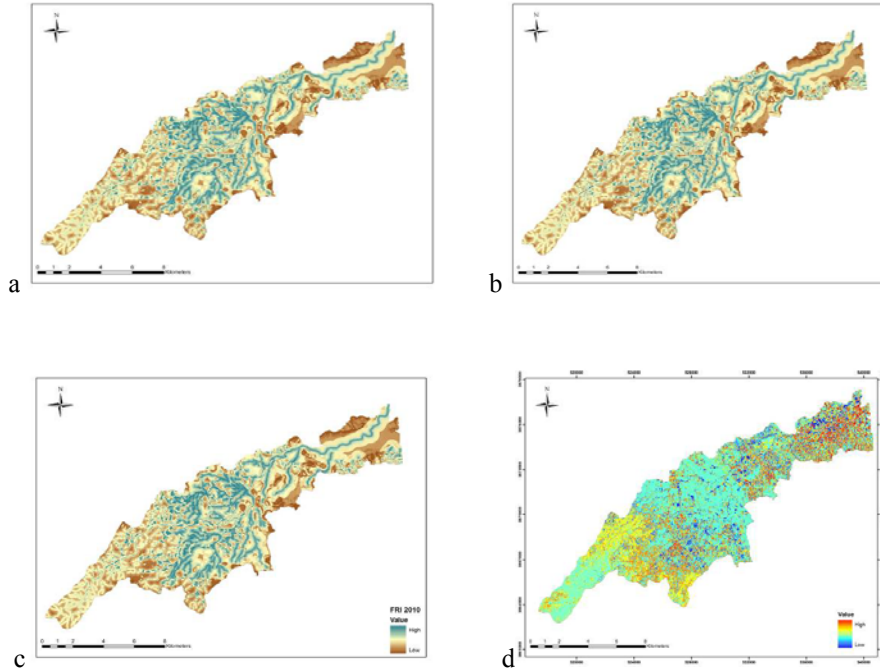


Figure 6. a) Flood Risk Index for the time period of 2000. b) Flood Risk Index for the time period of 2005. c) Flood Risk Index for the time period of 2010. d) Subtraction of 2000 from 2005 FRI layer.

6 CONCLUSIONS

In this paper flood risk assessment maps were constructed for the Yialias River basin in Nicosia Cyprus. Concerning the results of the study, the potential of remote sensing to study the drainage network in a watershed basin was highlighted. The updated network was imported in GIS environment and crucial hydrological parameters were calculated. According to calculations, basins with high bifurcation ratio, low stream frequency and low drainage density such as Yialias reflect the lowest flooding probability and the highest groundwater potential. On the other hand the Form Factor indicates a potential of basin to high side flow in shorter time period. However, the integrated study of the hydrological and geological regime denotes a basin with medium flooding potential. The diachronic land cover regime was searched through the use of multi temporal satellite imagery. The results revealed the major phenomenon of urban sprawl in the broader area during the period of the last 10 years. The three different land cover layers were imported with other parameters in GIS environment. The final FRI provided digital flood risk assessment maps. Subtracting the FRI maps of different periods the fundamental role of land cover regime was denoted.

The study demonstrated a fast and cost effective way to use GIS and remote sensing techniques for constructing an efficient flood risk map. At a next stage the flood hazard map can be incorporated to the regional land-use decision plan. This may help to reduce the potential flood risk at the area of Yialias River.

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REFERENCES

- Alexakis, D., Sarris, A., Astaras, T., Albanakis, K. (2009). Detection of Neolithic Settlements in Thessaly (Greece) Through Multispectral and Hyperspectral Satellite Imagery, *Sensors* 9, 1167-1187.
- Becker, A., Grunewald, U. (2003). Flood risk in central europe. *Science* 300 (5622), 1099.
- Bishop, M.P., Shroder, J.F., Bonk, R., Olsenholler, J., (2002). Geomorphic change in high mountains: a western Himalayan perspective. *Global and Planetary Change* 32, pp. 311–329.
- Fernández, D., Lutz, M., (2010). Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis, *Engineering Geology* 111: 90–98.
- Hadjimitsis, D. G., Clayton, C. R. I., and Hope, V. S. (2004a): An assessment of the effectiveness of atmospheric correction algorithms through the remote sensing of some reservoirs, *Int.J. Remote Sens.*, 25(18) : 3651–3674.
- Hadjimitsis, D. G., Clayton, C. R. I., and Retalis, A. (2004b): Darkest pixel atmospheric correction algorithm: a revised procedure for environmental applications of satellite remotely sensed imagery, *Proceedings 10th International Symposium on Remote Sensing, Proc. SPIE* 5239, p. 464.
- Hadjimitsis, D. (2010). Determination of urban growth in catchment areas in Cyprus using multi-temporal remotely sensed data: risk assessment study, *Nat. Hazards Earth Syst. Sci.*, 10, 2235–2240.
- Kouli, M., Vallianatos, F., Soupios, P., Alexakis, D. (2007).GIS-Based morphometric analysis of two major watersheds, Western Crete, Greece. *Journal of Environmental Hydrology*, v15.
- Martinez, J.M., Toan, T. (2009). Mapping of flood dynamics and spatial distribution of vegetation in the Amazon floodplain using multitemporal SAR data, *Remote Sensing of Environment* 108, 209–223.
- Mather, P., (1987). *Computer Processing of Remotely-Sensed images : An introduction*, Chichester, Wiley and Sons, 1987.
- Michaelides, S., Tymvios, F., Michaelidou, T. (2009). Spatial and temporal characteristics of the annual rainfall frequency distribution in Cyprus, *Atmospheric Research* 94, 606–615.
- Murck, B., Skinner, B., Porter, S. (1996). Environmental Geology. Wiley and Sons Inc. 535 pp.
- Ocalir, E., Ercosun, O., Tur, R. (2010). An integrated model of GIS and fuzzy logic (FMOTS) for location decision of taxicab stands, *Expert Systems with Applications*, 37: 4892 – 4901.
- Smith, A. *How to convert ASTER Radiance value to reflectance*. University of Idaho, <http://www.cnrhome.uidaho.edu/default.aspx?pid=85984>. 2007.
- Strahler, A.N., (1964). Quantitative geomorphology of basins and channel networks. In: Chow, V.T. (Ed.), *Handbook of Applied Hydrology*. Mcgraw Hill Book Company, New York.
- Ward, R., (1978). *Floods, A Geographical Perspective*. Macmillan Press, London.