MODELLING OF URBAN LAND USE AND ASSESSMENT OF FUTURE URBAN EXPANSION: APPLICATION IN THE MUNICIPALITY OF MYTILENE, LESVOS ISLAND, GREECE.

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EXTENDED ABSTRACT

In this study, remote sensing and spatial modeling techniques have been applied for the analysis and modeling of urban uses, observed during the time frame from 1984 to 2009, in the Kapodistrian Municipality of Mytilene, in Lesvos Island, Greece. Our scope was to capture and analyze the spatial pattern of urban uses in the area, in order to model the observed urban environment and predict its future expansion.

Undoubtedly, satellite data allow for mapping and monitoring of land cover changes, which occur due to anthropogenic interventions in the natural environment. In this study, Landsat satellite imagery was used, in order for past urban expansion to be mapped, after the interpretation of images for the years 1984, 1990, 2001 and 2009.

Based on the classified images, maps of the past were created, showing the changes that occurred to the built environment of the study area. These maps were used to calibrate a spatial predictive model, with the use of which we produced maps of expected future change to the year 2020, in the context of different policy scenarios.

In order to assess the spatial accuracy of the model, a probability map of urban change for 2009 was produced. Initially, inspection was made for the total of the modeled urban uses in relation to the total actual urban uses (map of historical data for 2009). The accuracy of the model was further asserted by comparing the areas of predicted changes to the areas of actual changes, for the reference year 2009.

In conclusion, we suggest that the combined approach of applying remote sensing and spatial modeling methods can be particularly useful for a better representation, understanding and modeling of the spatiotemporal changes occurring due to the process of urbanization. We believe that the proposed approach leads to a better understanding and promotion of urban dynamics and contributes to the development of alternative approaches to urban planning. By providing the ability to derive results through the application of various scenarios of urban growth in a region, such a model serves as a decision support tool as it aids in the understanding of the effects that would result from possible actions. Specifically, the simulation results under the two scenarios for the urban growth in the municipality of Mytilene shows great potential for use by managers in the region.

Keywords: spatial modeling, urban sprawl, cellular automata, SLEUTH model, remote sensing

1. INTRODUCTION

The term "urbanization" is used to refer to the people’s transition to cities and the transformation of the 'natural' landscape into urban (Mills 2007). That is, urbanization is considered as the conversion of the natural land to artificial which is characterized by man-made facilities. The definition of what is considered as an urban area, in contrast to other land uses, varies depending on the particular characteristics of the study area as well as on the targeting of each study. In general, an urban area is characterized by a structured soil, including the central city and its direct suburbs, which holds a specific socio-economic relationship with its surroundings.
The city can then be considered as an open and complex self-organizing system that is in a constant exchange of goods and energy with the hinterland and other cities. On the basis of this example of self-organized system, urban models were developed based on the technique of automatics, with Cellular Automata (CA) to be the simplest and most popular. Many urban CA models have been implemented over the past three decades which have proved useful for simulating the urban development in large cities (García et al. 2012).
The ability of CA to simulate urban development is based on the assumption that the urban development of the past affects the future patterns through local interactions between land uses (Santé et al. 2010). Remote sensing techniques on the other hand have already shown its value in use, both in the imprinting of land use changes as well as data sources for the analysis and modeling of urban growth (Batty & Howes 2001).
In most studies of urban land use change, Landsat satellite data are used, because of their uniqueness as a long period dataset with a medium spatial resolution and relatively consistent spectral and radiometric resolution (Weber et al. 2005; Yang et al. 2003). These data are of particular value and are offered in a wide time range, which is particularly useful for the detection of historical land use changes. Landsat satellites have the ability to supply us with historical image data of the Earth from the last 40 years.
Within that frame, a methodology is presented for the imprinting of urban sprawl observed in Kapodistrian municipality of Mytilene and for predicting its future urban expansion. The study area is the Kapodistrian municipality of Mytilene, located at the south-eastern tip of the island of Lesbos, and includes the city of Mytilene, which is the capital of the prefecture of Lesvos. It is mainly covered by large cultivated areas, the vast majority of which are olive groves. The rest of the vegetation of the area consists of coniferous forests, grasslands and scrublands.
The total area of the municipality is 108 km^2, while the actual population in 2001 was 40.500 inhabitants according to the census of the Greek Statistical Authority (ELSTAT).The municipality includes the island's airport and there is a significant urban growth and expansion, due to internal migration, mild tourist development and the recent construction of the Aegean University campus.
This work was originally held in 2010 in the context of MSc Thesis, and then (2012) has been further enriched by assessing the accuracy of the model used. The methodology applied in this study consisted of two main sequential steps: a) The mapping of land use using remote sensing, and b) The modeling of urban areas using the SLEUTH model.
SLEUTH is a CA model, which takes into account four types of growth: automatic / spontaneous, growth that takes place because of the spread of a new center / kernel, organic or edge growth and growth influenced by roads (spontaneous, diffusive, organic and road-influenced). All these growth rules are controlled by five growth coefficients that are applied sequentially in each cycle of growth: dispersion, breed, spread, road gravity and resistance in topographic slopes.
The model is implemented in two phases: the calibration, where it is being trained to reproduce the historical trends and growth patterns, and the prediction phase, through the simulation of historical trends in the future. The model can not only simulate the change of land use from non-urban to urban, but also other land use changes too.

SLEUTH was developed to simulate urban development in San Francisco Bay by Keith Clarke and his colleagues (Clarke et al. 1997; Clarke & Gaydos 1998). Since its first application in 1997, this model has been implemented in a number of areas of the United States and the entire world.

2. PREPARING INPUT DATA - SPATIOTEMPORAL DATABASE

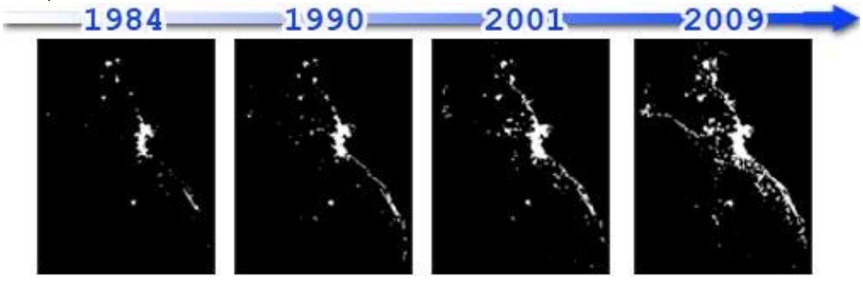
2.1. Creation of Geographic Temporal Data Base

Four satellite images of the LANDSAT Thematic Mapper were used with reception dates: 1984, 1990, 2001 and 2009. The Normalized Vegetation Index was calculated, and added as an additional channel in the images. The images were classified using the classification system of Corine Land Cover (level 3). The methodology of fuzzy supervised classification was used. The overall accuracy assessment of each classified image is shown in the following table (Table 1).

Table 1. Table of classification accuracy assessment

OVERALL CLASSIFICATION ACCURACY ASSESSMENT	
1984	77,33%
1990	80,00%
2001 (Corine 2000)	82,67%
2001 (Quickbird 2003)	84,00%
2009	72,00%

Layers of urban uses were then created after the reclassification of land uses that emerged with the application of supervised classification in Landsat images for the years 1984, 1990, 2001 and 2009. The land use maps were converted into binary layers for the classes of urban / non-urban land. The slopes were created by using the digital terrain model ASTER GDEM (from Terra satellite, through the sensor ASTER), with spatial analysis of 30m. The General Urban Plan of the Municipality of Mytilene was used as a data source, for determining the areas which are excluded from urbanization. A GIS layer was created illustrating Special Protection Areas for the study area. In specific, 31 areas were identified, where urbanization may strictly not happen or advance. In addition, some open spaces and parks in the city of Mytilene, which should be excluded from urban development, were added to that layer. The road network of the study area, of years 1990 and 2009, was used too.



Picture 1. The input data of urban uses in SLEUTH model

2.2. Creation of Scenarios

Two scenarios were designed to simulate the spatial pattern of urban expansion under different conditions. The first scenario "Free urban sprawl" involves the continuous expansion of urban areas, without any restriction, similar to the trends of the past. The excluded layer defined only the sea area, where urban expansion is impossible to occur.

The second scenario "Urban sprawl by strict protection of environmentally sensitive areas," in which urban development in certain areas is restricted, is oriented towards the protection of the natural environment. The excluded layer defined Special Protection

Areas where urban expansion was considered impossible. All excluded areas took the value 100 corresponding to 100% exclusion from urban development.

2.3. Customizing Historical Data - Calibration

The main assumption of the SLEUTH model is that the way an area has changed in the past is the rule for change in the future. An important tenet of the model is that by calibration of how an area has changed in the past, it can produce a reasonable prediction of future change (Clarke et al. 1997). Thus, the purpose of the calibration phase is to derive a set of values for growth coefficients that can effectively simulate the observed urban growth during a period of the past.
The calibration process is started for most past data and generates growth cycles. When one complete cycle has a corresponding control year, a simulated image is produced while values are calculated for eleven statistical indicators (metrics), to control best fit of the spatiotemporal data entered into the model.
During the three phases of calibration (coarse, fine and final) a set of values for each coefficient was selected using Lee Sallee metric that best described the historical data of urban uses for both scenarios. In addition, to assess the accuracy of the model, adjustment of historical data for the years 1984 to 2001 was made, with control years 1984, 1990 and 2001, so as to predict urban change for the year 2009.

2.4. Forecasting coefficients

After calibration an average of each scenario's ending coefficient values, or best solution set (BSS), was used to initialize a forecast for both scenarios. Each set of values was used to initialize a run of simulated growth from year 2009 to 2020. A frequency histogram depicting coefficients' average values of the last year of our historical data (Figure 1) was created and evaluated to observe the dynamic behaviour of forecasted urban growth.

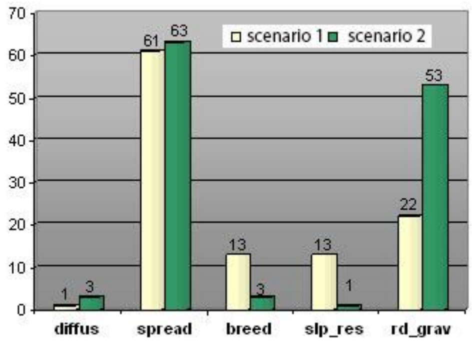


Figure 1: Coefficients' average values

As is demonstrated by the above histogram, high score for spread parameter for both urban growth scenarios reflects the high probability of urbanization on the periphery of existing urban centers. Also, the rather high score of the road network gravity in urban sprawl (rd_grav) is indicating that the forecasted urban growth has clearly, significantly been affected by the road network in the area. Specifically, for scenario 2, the effect of the existing road network in urban sprawl is further reinforced.

3. RESULTS

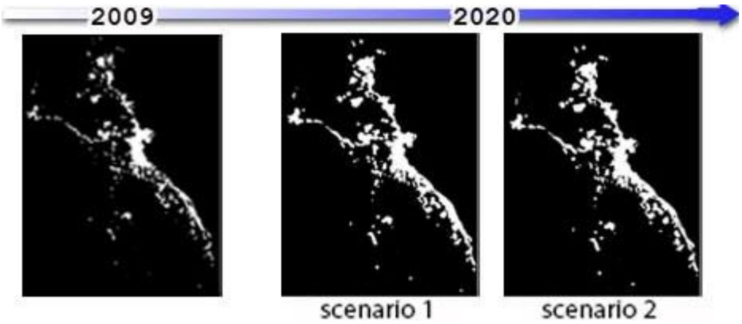
3.1. Forecast Maps

The resulting prediction of future urban growth is a probability map for each cell / pixel to be urbanized sometime in the future, assuming that the same urban development trend is

still in force, as was in the past (Herold, et al., 2003). The probability forecast maps were brought into a GIS and image analysis techniques were applied.
The images were classified by probability and predicted results were quantified. The pixel counts as well as the area in square kilometres of each of these probabilities are listed in Table 2.

Table 2. Table of probabilistic pixels - extent

URBANIZATION PROBABILITY	Number of pixels		Area in km^2	
	scenario 1	scenario 2	scenario 1	scenario 2
95-100%	3517	3750	3,16	3,37
90-95%	1573	1444	1,41	1,29
80-90%	1813	1617	1,63	1,45
70-80%	1313	1176	1,18	1,05
60-70%	1092	953	0,98	0,85
50-60%	992	864	0,89	0,77
Urban areas 2009	11316		10,18	



Picture 2. Extent of urban uses 2009 - 2020

Under scenario 1 (Free urban expansion without any restriction), the model predicts that more than 5800 pixels or ~ 4.6 square kilometers of the study area, which is not accounted for urban uses will be urbanized with a probability of over 90% by the year 2020. As for scenario 2 (Urban sprawl by strict protection of environmentally sensitive areas), 5194 non-urban pixels have the same probability to be urbanized by the year 2020. Also, by observing Table 2, it becomes clear that in scenario 1, the overall prediction is that a greater number of pixels have a chance to be urbanized by the year 2020.
Furthermore, for both the 2 scenarios, a large amount of available flat land with small topographic slopes, which already includes some urban uses, displays a probability greater than 50% for urbanization. It is noteworthy that the majority of these changes are foreseen in the periphery of the current urban centers, with a probability of 90% or greater. That is, urbanization will occur in the surroundings, around all the existing urban uses.

3.2. Quantification of Changes

The total projected number of pixels as well as the area in square kilometers up to 2020 is presented in the following table (Table 3). Also presented in the same table is the calculation of the temporal variance in the urban tissue predicted for the year 2020 compared with 2009. Finally, areas for each land use category (for 2009) that would turn into urban uses were estimated (Table 4). The results of the simulations for both scenarios show the amount of change of urban uses at the expense of other land uses, in accordance with current trends.

Table 3. Table of total pixels- extent

URBAN AREA	Number of pixels		Area in km^2	
	scenario 1	scenario 2	scenario 1	scenario 2
2009	11316	11316	10,18	10,18
2020	21616	21120	19,45	19,00
2009 to 2020	10300	9804	9,27	8,82

Table 4. Table of land use change to urban uses

MODIFICATION OF OTHER LAND USES INTO URBAN	Area in km²	
	scenario 1	scenario 2
Bare land	0,06	0,05
Low vegetation	2,10	1,89
Various crops	2,10	2,04
Forests	0,17	0,12
Groves	4,84	4,71
TOTAL	9,27	8,82

The calculation of the diachronic difference of the projected urban tissue for the year 2020 compared to 2009 reflected in the following table (Table 5) compared with the observed difference between the years 1984 to 2009.

Table 5. Area of urban uses 1984 - 2020

URBAN AREA	Area in km²		Percentage of total municipal area	
1984	2,71		2,51%	
1990	4,19		3,88%	
2001	6,04		5,58%	
2009	10,18		9,43%	
2020	scenario 1	scenario 2	scenario 1	scenario 2
	19,45	19,00	18%	17,6%

3.3. Model Accuracy Assessment

In order to assess the spatial accuracy of the model, a probability map of urban change for the year 2009 was generated by applying 100 Monte Carlo iterations with one step increment. As forecasted, urban uses were considered all those pixels that exhibit a chance of "urbanization" of over 50%. Simulated urban uses for the year 2009 were compared with the actual urban uses in pixel scale.
The accuracy was assessed using random reference pixels, by choosing a sample of 500 pixels from the entire image, 250 pixels from each category (urban, non-urban). Indicators Overall Classification Accuracy and Overall Kappa Statistics were used to assess the accuracy.

Table 6. Table of spatial accuracy assessment of totalurban uses

PIXEL CLASS	URBAN AREA 2009	MODEL ESTIMATION 2009	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistics
Non-urban	282	250	246	87.23%	98.40%	0.9633
Urban	218	250	214	98.17%	85.60%	0.7447
TOTAL	500	500	460			
OVERALL ASSESSMENT			92.00%			0.84

As shown in the table above (Table 6), the overall accuracy of simulated urban growth for 2009 is equal to 92%. Also the Kappa Statistics value was equal to 0.84 indicating that the map of the simulated urban and non-urban uses avoided the 84% of the errors that a completely random classification would have. Estimated kappa statistics values for urban and non-urban uses are equal to 0.74 and 0.96 respectively.
Thus initially the whole of the modelled urban use areas were checked for concurrence in relation to the total actual urban use areas. The accuracy of the model was further asserted by comparing the areas of predicted changes to the areas of actual changes, for the reference year 2009. Three categories of pixels were created representing: observed urban uses in 2001, additional urban uses for the year 2009, and non-urban uses. A sample of 501 pixels from the entire image was chosen, 167 pixels from each category.
As seen by the table below (Table 7), the overall accuracy was found to be 82.24% and 51% after the inspection for the areas where the change referred to, while the statistical kappa was calculated to 0.73 and 0.4 respectively.

Table 7. Table of spatial accuracy assessment of changes

PIXEL CLASS	URBAN AREA 2009	MODEL ESTIMATION 2009	Number Correct	Producers Accuracy	Users Accuracy	Kappa Statistics
Non-urban	247	167	165	66.80%	98.80%	0.9764
Urban 2001	165	167	162	98.18%	97.01%	0.9554
Urban 2001-2009	89	167	85	95.51%	50.90%	0.4029
TOTAL	**501**	**501**	**412**			
OVERALL ASSESSMENT			**82.24%**			**0.73**

The outcome of the spatial accuracy assessment in relation to forecasted to-be-urbanized areas is also underpinned by the numerical devaluation of the simulated urban changes. The actual urban uses for the year 2009 amount to 11316 pixels, while the model predicted that urban uses for the same year will be represented by 9384 pixels (underestimation of 1932 pixels). In other words, a proper valuation of urban uses by 83% was made. Furthermore, knowing that the actual urban uses for the year 2001 amounted to 6707 pixels, the actual growth of urban uses by the year 2009 was 4609 pixels, while the model predicts that 2677 pixels will be "urbanized" by the year 2009. In other words the transition was correctly estimated by 58%.

The above underestimation reflects to the inability of the model to predict the emergence of new urban facilities in the area without direct relation to existing infrastructures (referred to as spontaneous growth). Something that is considered reasonable, as it must be noted that the projected change for 2009 was made after the assumption that urban sprawl has a linear relationship with the past, namely that the trend of the past can be used to reproduce the trend of the future. The adjustment of the model to historical data would probably have been improved if an intermediate control year between the years (2001-2009) was included, in which period there was a sudden change in areas where no urban facilities existed prior to year 2001.

5. CONCLUSIONS

In the present study we used Landsat satellite images, and created maps of land use changes for the years 1984, 1990, 2001 and 2009, which we used to calibrate an urban prediction model. However, after evaluating model's spatial accuracy we found that under the main assumption of the SLEUTH mode (that the way in which an area has changed in the past is the rule for change in the future expressing thus a linear relationship between past and future), the model fails to provide high accuracy with the future change if an abrupt change appears in a short time. Undoubtedly, the linearity between past and present does not exist and cannot accurately describe the urbanization trends. For this reason the calibration objective should be to recognize and reproduce properties of multidimensional space that represent the path of urban expansion over time with greater accuracy. Therefore, if there are non-linearities in this path, the time series of monitoring data is critical for the accuracy of the model.

In any case, it should be noted that the assessment of future urban expansion of the Municipality of Mytilene in 2020, is an implementation example of SLEUTH model, in order to assess/demonstrate the interpretive / research potential offered by its use.

It should be noted that in most of the previous studies, analyses of land cover change in urban environment were conducted either in large metropolitan cities, namely at the level of the city, or within a natural landscape, such as a watershed or habitat. The research on urban expansion has taken place in the limits of large cities with rapid urban sprawl, while little has been done in relation to medium-sized cities. The application of the SLEUTH model in the study area as a single administrative set may more accurately describe the driving forces leading to this observed urban spatial pattern. This type of urban development is quite different from those usually simulated by urban CA models.

A single administrative set (such as the Kapodistrian municipality of Mytilene) can be seen as a system, where its interior is interacting with all those variables that drive the urban hot spots at specific places. While interacting with other agents outside the system, which strongly affect the urban profile (the non-resident population of the municipality of Mytilene during the winter months consist primarily of students of the University of the Aegean, while during the summer by tourists).

The island environment and particularly environmentally sensitive areas of the islands are characterized by a number of features as highlighted by Hatzopoulos and Efthimiatou, covering both the natural and human environment (small population size, seasonal fluctuations) and growth (small economy, weakness of public infrastructure, limited private investment, high transport costs, pressure from tourism, limited diversification of production and exports, etc.) (Hatzopoulos & Efthimiatou 2010). Therefore, socioeconomic data could be used in order to assess the factors that characterize the urban sprawl of the study area (e.g. objective values, geographic mobility, income, etc.).

As for the use of remote sensing data for mapping urban environment, which is generally characterized by very heterogeneous surfaces with significant between and within the pixel changes, the potential to detect changes is inherently limited by the spatial resolution of digital images. However, we can simulate the dynamics of land use in unstructured and structured environment using medium spatial resolution imagery such as Landsat when the goal is to formulate policy.

We conclude that the results of modelling process with SLEUTH model are useful for comparing the effects between different scenarios. Providing the ability to obtain results through the application of various scenarios of urban growth in a region, the model serves as a decision support tool as it helps in understanding the effects that would result in possible actions.

For all these reasons, we believe that providing the geographic distribution of urban uses in an area is an extremely interesting field of study with many different perspectives. In specific, using spatiotemporal data and other methods of spatial analysis could be the subject of future lengthier and more detailed study.

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