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The effects of socio-economic variables in urban growth simulations

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Abstract

Urban sprawl phenomenon is one of the higher threats to the preservation of soil resources. Soil consumption is strongly related to social and economic factors that characterize a territory. Several models have been developed to recreate future scenarios based on past expansion development dynamics. Among cellular automata models for urban growth simulation, SLEUTH is considered as an effective tool to support urban management. However, the model does not explicitly include demographic dynamics and socio-economic ones. This paper compares the results of two different simulations performed on the same study area through the SLEUTH model. While the first simulation is performed using the classical method of calibration of the model, the second one proposes the inclusion of some socio-economic variables within the simulation process. The results show a better match with the actual development trends of settlement by the simulation that takes into account the social and economic aspects of the analysed territory.

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Keywords: Land use change models; soil consumption; urban policies; socio-economic variables; urban sprawl; AHP;

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1. Introduction

The environment is the setting in which naturalistic, landscape, anthropological and economic elements relate to each other, to varying degrees. Urban areas as places of concentration of the world's population define territorial areas that condense high levels of pressure on the ecosystem; and their development creates growth that is directly proportional to such pressure. Usually, one thinks of urban sprawl as a phenomenon characterized by a vigorous expansion of urban areas, a symptom of erroneous economic choices (Brueckner, & Fansler, 1983). In more or less negative ways, they impact urban energy efficiency, producing psychological and social costs that result in the loss of a sense of community while contributing to the decline of the compact city (Ewing, 1994). It should be recognized that the processes of urbanization and settlement transformation are encouraged not only by economic and financial dynamics, but, above all, by demographic dynamics. These, in addition to defining the increase or decrease in the population, explain more fully the transformation of a society and its needs. Nevertheless, in recent decades urban sprawl has presented notable developments where no significant demographic growth has been recorded (Nolè, Murgante, Calamita, Lanorte, & Lasaponara, 2014). Consequently, it is essential to make judgments based on further dynamics that are directly related to demography and urbanization and trigger the phenomenon. The literature describes numerous models that can effectively simulate urban growth. However, the main criticism of these models is related to their weak ability to integrate explicit variables in the simulation process, not so much ones that are spatially explicit as those of a socio-economic nature. This paper intends to use the socio-economic variables that have the greatest impact on the process of urban expansion within the known SLEUTH model. The results show that simulations that consider these variables ensure a greater degree of coherence with respect to the actual socio-political scenarios that guide the transitions between land use classes.

2. Materials and Methods

2.1. SLEUTH model

The literature recognizes several groups of geo-computational methods applied to the modeling of urban phenomena (Clarke & Gaydos, 1998; Manganelli, Pontrandolfi, Azzato & Murgante, 2014; Von Neumann, 1996). Cellular automata methodology was developed in 1940 by John von Neumann. In recent times, due to the prodigious development of hardware technology, wider applications of it have been developed (Caglioni, Pelizzoni, & Rabino, 2006).

Among the cellular automata models for the simulation of changes in land use, and for modeling dynamic urban models (White, & Engelen, 1993; Papini, & Rabino, 1997). Sleuth is one of the best known. It is a probabilistic model with Boolean logic that describes four behavioural space models that predict a change of land use or urban growth (Martellozzo, & Clarke, 2011), based on five parameters (Ding, & Zhang, 2007): dispersion, breed, spread, slope, and road-gravity. The growth cycle adopted by the model as a unit of time corresponds to one year; for each unit of time the model processes four types of growth dynamics in urban areas, classifiable as: spontaneous growth; the emergence of new centers of expansion; growth on the edge; and growth influenced by the presence of road infrastructure (Clarke, Hoppen, & Gaydos,1997). SLEUTH is an acronym that defines the six spatial inputs that form the layers required by the model. In order, they are: Slope, Land Use, Excluded, Urban extend, Transportation network and Hill shade. The robustness of the model is based on its application as an effective support tool of urban management and experimentation with complex urban structures (Candau, 2003). Calibration explores all the possible iterations of the five parameters that drive simulation. Therefore, it is particularly complex in computational and temporal terms. The values during calibration are constantly modified through a journey that runs from the first date to the end date of the forecast. The parameters used to measure an improved calibration at the end date are considered, and they will initialize the forecast. Several approaches have been used to restrict the space of coefficients; weighing-up a number of parameters more heavily than others and putting them in order according to only one metric (NCGIA, 2011). Each metric represents the value between simulated growth and the growth evaluated in the control years. In particular, Optimum SLEUTH Metric (Dietzel, & Clarke, 2004), adopted to limit the range of the coefficients, is produced by: a comparison (set of molded end pixels); the population (number of urban pixels); the group (pixels along the edges of urban centers); the edge (urban perimeters); the average slope; and average metrics X and Y.

2.2. Analytic Hierarchy Process

Sleuth provides a weak user-interaction model. In fact, the only way the user can influence the simulation is through the construction of input layers. In particular, the construction of different simulation scenarios occurs through the realization of excluded alternative layers. The excluded layers define the spatial limitations of urban growth in a territory. The layers, in raster form, provide each cell with a value, from zero (no limit) to 100 (maximum exclusion). The use of socio-economic variables in the simulation is, therefore, necessary, in order to develop a methodology for their inclusion within the excluded layer. In particular, this paper proposes the use of a technique of Multi-Criteria Decision Analysis (MCDA): the Analytic Hierarchy Process (AHP), created in 1980 by Saaty, and subsequently formalized as an axiomatic theory (Saaty, 1980; 2000).

2.3. Study area and Data

Vulture Alto-Bradano defines a mountain district located north-east of the Basilicata (Italy). This area incorporates 19 municipalities. The Vulture area is characterized by substantial demographic stability. Positive demographic trends have been recorded recently in the larger municipalities. These enable us to estimate the subsequent expansion and transformation of the settlement structure, especially along the slopes.

As previously specified, the SLEUTH model requires the input of six factors, in order to characterize the dynamics of settlement development, all duly converted to the Graphics Interchange Format (GIF). The land use and urban extension maps (Fig.1) cover four dates necessary for the implementation of the SLEUTH model.

These were derived from the supervised classification of remotely sensed data using the algorithm SMAP. Satellite images Landsat 4-5 TM (Thematic Mapper), acquired for free from (http://earthexplorer.usgs.gov/), were used for the land classification. To ensure continuity, the images were taken in summer for 1985, 1993, 2002, 2010.

The assessment of changes in the area between 1985 and 2010, compared with identified land cover, has highlighted the extension of urban areas at the expense of agricultural land, rather than bare land, over this 25-period. The maps show the changes that have occurred in the area between 1985 and 2010. Relative to the identified land cover, the maps highlight the expansion, contrary to all predictions, of urban areas at the expense of agricultural land, rather than bare soil, over 25 years. It is interesting to note, when observing surface areas (Km2) and changes in land cover (%), that the urban class witnessed a steady increase from 20,62 km2 in 1985 to 37,41 km2 in 2010 (Table 1)..

Table 1. Summary of the surfaces of each class for 1985, 1993, 2002 and 2010.

	1985		1993		2002		2010	
	Surface (sq.km)	%	Surface (sq.km)	%	Surface (sq.km)	%	Surface (sq.km)	%
Water	3,48	0,22	2	0,12	2,78	0,17	4,19	0,26
Wood	148,76	9,31	150,26	9,43	208,86	13,08	180,41	11,3
Sparse vegetation	142,09	8,9	248,38	15,59	46,32	2,91	196,56	12,31
Urban	20,62	1,31	26,96	1,69	28,31	1,78	37,41	2,34
Cultivate soil	347,26	21,86	174,69	10,96	533,07	33,45	419,85	26,3
Plowed soil	194,05	12,17	470,31	29,51	176,6	11,17	379,87	23,79
Permanent meadows	599,15	37,56	304,06	19,08	444,24	27,81	270,68	16,95
Bare soil	138,17	8,67	216,93	13,61	153,41	9,63	107,72	6,75

This increment is held to have occurred at the expense of areas occupied by permanent meadows and the average percentage of bare soil. It is possible to confirm that around 17 km^2 of territorial surface has been urbanized, an increase of 1%, affecting farmland and permanent grassland.

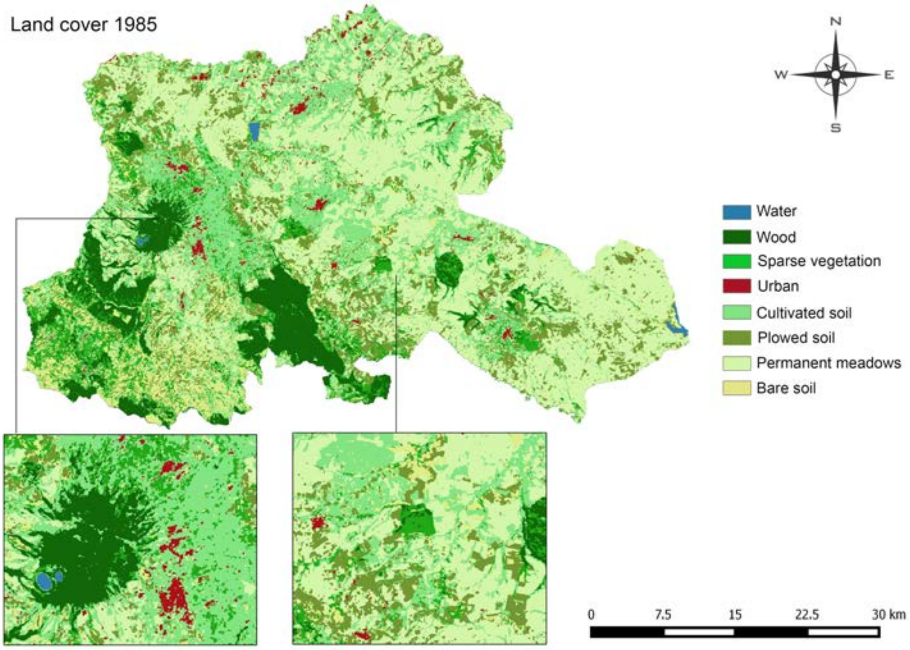

Fig. 1. Details of Land cover at 1985.

It is interesting to note that the growth of urban areas does not always coincide with an increase in the population. This can be observed by comparing the growth of urban areas from 1985 to 2010 with data supplied by ISTAT (Institute of Statistics), relative to the population censuses of the 19 municipalities that comprise the mountain district in the considered period (Fig.2).

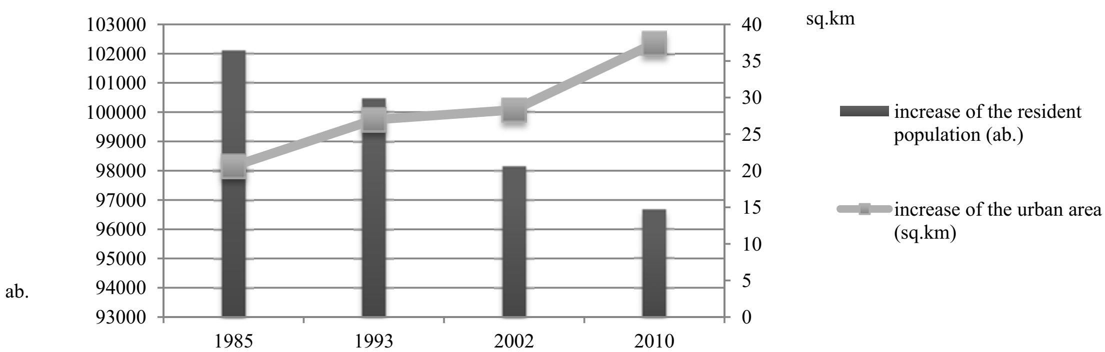

Fig. 2. Variations of the eight classes that occurred between 1985 and 2010.

The images of the transportation network are derived from the processing of shapefiles containing the geographical distribution of road infrastructures, downloaded from the Geoportal of the Basilicata (http://rsdi.regione.basilicata.it/webGis2/SpecificaDBT.html). The same source has provided the data necessary to develop a geomorphological analysis for the construction of the Hillshade and Slope layers. The construction of the excluded layers has been more complicated. In particular, two different layers were created, to assess the effects of socio-economic variables on simulation. The first layer was built using only areas of value or at risk, obtained through the processing of the Regional Soil Map for the Province of Potenza. For each geographical area in the territory, the map determines the regulations for conservation, new plants or transformations. The second layer complements the first, with the addition of appropriately weighed socio-economic variables. The definitions of the variables that affect the urban sprawl were informed by the data in ISTAT's 15th General Census of Population and Housing, dated October 9, 2011 (http://dati.istat.it/). Four variables in particular show a relationship with the urban sprawl and cover the same historical period. The censuses of 1991, 2001 and 2011 have been considered for: the demographic component, concerning the number of households in the area; socio-economic components relating to the number of individuals employed in the active population and level of education; and anthropic components covering the proportion of empty homes in relation to total dwellings. At the same time as the collection of census variables, the Territorial Base of the Basilicata Region (http://www.istat.it/it/archivio/104317) was implemented in the GIS environment. The geographic data is in the shapefile format and can be downloaded as double geographic projections (SR ED 1950 Zone UTM WGS 84 UTM Zone 32n and 32n).

3. Results and discussions

3.1. Multicriteria Analysis

Data concerning the variations in households, the level of employment, the level of education and the proportion of empty homes have been used for the creation of the second scenario. These socio-economic variables, related to the urban sprawl phenomenon, were first catalogued and classified for each municipal area in the territory under investigation. Subsequently, in order to assess the trends in the period 1991-2011, mathematical calculations were carried out to determine the mean, variance and standard deviation. Estimations of the variation of each of the variables were made on the assumption that any increase or decrease has an exponential relation with urban growth rather than a linear one. To not trivialize the data, each variable has been multiplied for multipliers of 1.10 in case of an increase and multipliers of 0.90 in case of decrease. Subsequently, each variable was normalized into a range between 0 and 100. For each variable, a raster map was created. An AHP process has been developed considering both socio-economic variables maps and the territorial exclusions used in the first SLEUTH simulation. These cannot be omitted because they are linked to the decision-making dynamics. In the definition of the matrix the weights assigned to each variable were defined according to specific evaluations by a panel of experts in technical-scientific disciplines, subservient to spatial planning (Table 2), which resulted in a maximum eigenvalue of λ = 5,261.

Table 2. Pairwise comparison matrix.

variables	excluded	empty dwellings	households	employed	education level
excluded	1	3	2	7	7
empty dwellings	0,333	1	3	5	5
households	0,5	0,333	1	3	2
employed	0,143	0,2	0,333	1	2
education level	0,143	0,2	0,5	0,5	1

CI, CR and RI were calculated from the matrix, resulting respectively in 0,065, 0,058 and 1,120. They respect the previously defined thresholds.

The excluded layer for the second scenario has then been developed through a linear weighted combination of each of the considered weighted variables. Observing the two exclusion maps is possible to graphically appreciate the difference between the two layers used in the first and in the second simulation process (Fig. 3).

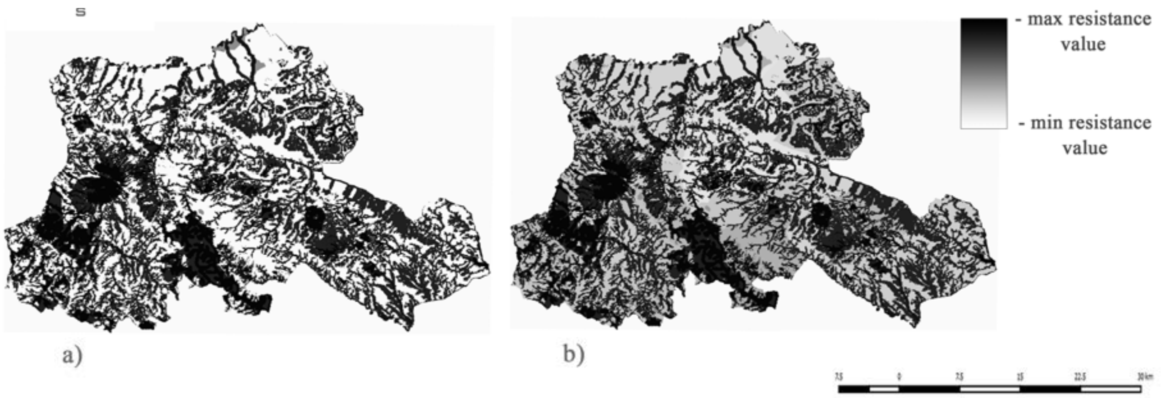

Fig. 3. Excluded layers a) with and b) without the socio-economic variables.

3.2. Simulation

Information obtained from the first simulation performed through the excluded layer containing only the environmental and landscape constraint has confirmed some of the hypothesized forecasts. A simulation has been carried out up to 2035. The result shows an increase of built-up areas especially near the already existing residential areas. The increased densification of urban confirms that the conurbation phenomenon is a reality that over the next 25 years could spread. Built-up areas will grow going from 38.47 to 72.79 km2 2011 km2 2035.

A second simulation has been carried out considering the excluded layer that was built through AHP, pondering the effects of socio-economical variables on urban growth.

Analysing both predictions from SLEUTH model is possible to compare the results obtained (Fig. 4).

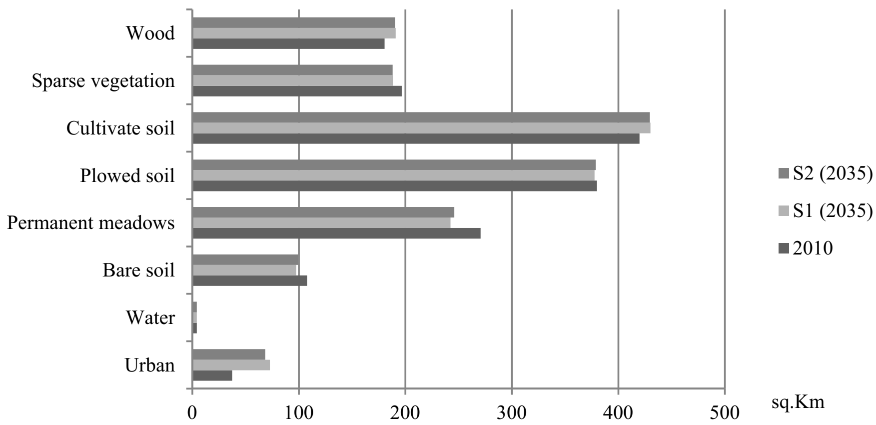

Fig. 4. Comparison of the eight classes of land cover in 2010 and 2035 without socio-economic variables (S1) and inclusion of socio-economic variables (S2).

Comparing the eight land cover classes analysed respectively in 2010 and in 2035 considering S1 (processing without the inclusion of socio-economic variables) and S2 (preparation containing socio-economic variables) emerges how marked is the increase in urban areas from 2010 to 2035 in both S1 and S2. The difference is perceptible between the two forecasts; in the one that includes the socio-economic variables, the increase of the urban areas was slightly lower. This shows how the considering socio-economic variables in the simulation had deep impact in simulating the dynamics of urban sprawl, ensuring consistency between the simulation results and the actual development models of urban areas.

Figure 5 show a comparison among the increase of urban areas obtained from both simulations and the expected variations of the resident population in the examined territory. Clearly, the discrepancy between the increase of urbanized areas and declining population will become even more evident. Nevertheless, S2 has leakage values settlement lower than S1. This shows a greater aptitude of S2 to adapt to the real urban growth dynamics, confirming how the development of urban areas is strongly influenced by their political and economic contexts of each reporting period.

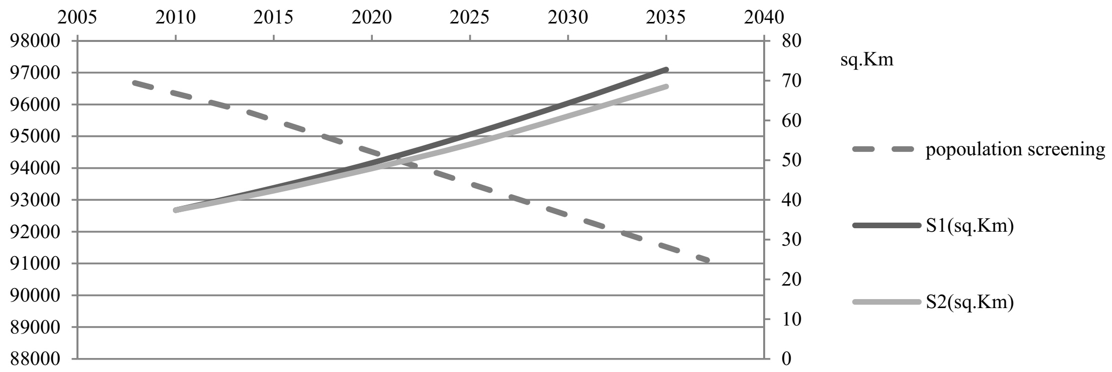

Fig. 5. Comparison of the increase in value of urban areas obtained the two S1 processing (no socio-economic variables) and S2 (with socio-economic variables) and the forecast change in the population.

4. Conclusions

The expansion of urban areas and soil consumption are growing phenomena affecting the entire national territory; more often than not is a practical connection between the needs of urbanization and sustainable development of the territory (Tajani, & Morano, 2015). This paper highlights the role that the population and its distribution in the regions, together with the social and economic dynamics, play in the processes of urban sprawl. Specifically, two scenarios of urban growth were developed using a proven to cellular automata model (SLEUTH) effectiveness in determining future trends of urban sprawl phenomenon (Amato, Maimone, Martellozzo, Nolè, & Murgante, 2016). The first scenario was obtained by the classical development of the model considering as limitations to the expansion of settlements only the environmental components and the constraints due to national and regional laws. The second scenario was enriched considering some socio-economic variables, whose municipal-scale evolution and diversification are expected to influence the development of urban areas. This is because it is believed that the redistributive processes of the population lead to reorganize territorial functions leading to increases or decreases of urban sprawl. The surveys were conducted in the mountain district of Vulture Alto-Bradano (Basilicata Region, Italy), an area with precise environmental characteristics and peculiar forms of settlement than the rest of the region. The results show that the use of socio-economic variables changes the future scenario curbing the urban sprawl. The reduction of the phenomenon is mostly related to the reduction of households and of population, as well as to an increase in the level of education that will probably lead to further depopulation, in most of the municipalities included within the study area (Amato, Pontrandolfi, & Murgante, 2015). However, employment levels and the increase in empty dwellings concentrated in compact urban cores induce although minimally to increased mobility and the development of neighbouring areas of urban settlements. The development of urban sprawl measured in both the simulations scenarios, is still a significant phenomenon when compared with the population dynamics forecast, which shows a dramatic decrease compared to the amount of urban areas forecasted. The scenario obtained considering socio-economic variables is closer to the real possibility of conceivable development. Therefore, consider the socio-economic dynamics is useful both to improve the supply of services in the territory and to permit the establishment of specific responses and concrete actions to limit the phenomenon of dispersion settlement, providing a useful aid to decision-making process.

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