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Supporting planning activities with the assessment and the prediction of urban sprawl using spatio-temporal analysis

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ABSTRACT

The inestimable value of soil is exemplarily summarized in the definition provided by the European Union (2006), which considers it as "the upper layer of the earth's crust, formed by mineral particles, organic matter, water, air and living organisms".
The importance of soil protection is now universally recognized, but despite a lot of debates and principle's enunciation, in the last decades soil was consumed at a rate of 8 m^2 per second. The aim of this study is to propose a model which, on one side, is able to measure variations occurred in land use, and, therefore, to determine soil consumption, and, on the other side, is capable to predict future changes. Specifically, a simulation model has been proposed based on two methods: Joint information uncertainty and Weights of Evidence in order to analyse and predict new built-up areas. The proposed model has been applied to Pisticci Municipality in Basilicata region (Southern Italy). This area is a significant example, because of its high landscape value and, at the same time, of a lot of developing pressure due to touristic activities along the coastal zone.

1. Introduction

For more than a decade, the European Union has recognized soil as a common good and considers it as a finite resource with an inestimable value. Consequently, soil is strongly linked to agricultural and zootechnical production, and therefore it intensely influences human nutrition.

The current gradual and steady world population growth is mainly due to the introduction of intensive farming technologies, which produced maximum exploitation of soil potential. The cultivation of a single plant species (monoculture), on one hand ensures a greater amount of food production, whilst, on the other hand has a high environmental cost, using at a high extent petroleum derivatives to move machinery, to fertilize and protect crops from pests. It started following the end of Second World War, and, together with the processes of market liberalization and globalization, it has led to a growth of food production by 140%, 200% and 280% in Africa, Latin America and Asia, respectively. Agricultural industrialization has produced two particularly effective consequences. The first one is related to occupation. The use of machinery for agricultural production has greatly reduced labour supply in the sector: in Europe 44% of the land is cultivated, but primary sector contributes only to 5.5% of employment.

The second effect is the abandonment of countrysides and the connected-urbanization process of rural population. In Italy, from 1951 to 1991 employees in agriculture passed from 44% to 9% of the population. This demographic phenomenon has developed in parallel with the expansion of cities and settlements.

For this reason, today the main threat to agri-food sector is represented by the expansion of urban areas, because it occurs mainly with great disadvantages for rural areas. This point has great importance, because a decrease in available fertile land means a weakening in productive potential of a country and an amplification of the dependence by food and forage, increasing transport and, consequently, pollution. Soil, however, is not only the place for agriculture. It is also the location of energy and matter exchanges with other environmental compartments.

It is an open system, and the main biogeochemical cycles pass through soil. Soil is actively involved in the hydrological cycle, because it intercepts most of the water derived from precipitation. Sliding surface is strongly influenced by soil use. Paved or built areas limit or eliminate soil absorption capacity by rainfall. In land use planning, it is important to consider water surface drainage, because it affects erosion and flooding. Carbon cycle is the second biogeochemical cycle where soil plays a crucial role. The greatest amount of carbon is not concentrated in the atmosphere, but in forests and soils. It is estimated that the amount of carbon dioxide contained in forest biomass and in forest humus is 1.5-4 times higher than carbon dioxide contained in the atmosphere, respectively (Zampogno and Cattaneo, 2012). Given the enormous amount of carbon stored in the soil, land use change can lead to a significant increase in CO_2 emissions in the atmosphere.

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In several local situations, soil consumption is no more the result of a real need, as in the past, because of significant population growth phenomena or accelerated urbanization process. Today soil consumption is often linked to poor public governance of environment and cities and, also, to speculative real estate projects and to unsolved problems of urban rent.

In September 2011 the European Commission (2011) communicated to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions the document “Roadmap to a Resource Efficient Europe”. Paragraph 4.6 of the document, "land and soils", states that "if the target is to develop a clear path that leads us, by 2050, not to build more in new areas, it is necessary that in the period from 2000 to 2020 the employment of new land is reduced by an average of 800 km^2 per year".

In many areas the soil is irreversibly eroded or contains very low amounts of organic material; problems further increase if considering the soil contamination.

The inestimable value of soil is exemplarily summarized in the definition provided by the European Union (2006), which considers it as "the upper layer of the earth's crust, formed by mineral particles, organic matter, water, air and living organisms".

Among the policies activated in Europe to control soil consumption, four main action strategies can be distinguished (Salata, 2012):

- soil consumption measurement and control at regional scale, defining strategic guidelines to be applied at the local level;
- creation of local agencies for existing urban areas development and revitalization;
- redefining the taxation model of land to discourage consumption of new soils and reduction of municipalities dependency on incomes produced by local taxes;
- definition of rules within the plans at municipality scale discouraging consumption of soils.

Policies adopted in the United Kingdom and Germany can represent important guidelines.

In recent times the UK government tried to limit processes of land use change through a qualitative and physical-morphological management of the phenomenon, while in Germany an annual limit to land transformations has been imposed in each administrative region.

Despite the problem of soil consumption containment has been widely discussed in Italy, this country was unable to produce effective measures aimed to limit the phenomenon. This inability can be interpreted as a consequence of a cultural deficit, due to the missing awareness that soil is a common good, a finite resource, and its reduction implies a significantly negative consequence at both short and long terms.

Water and air are common goods, they are protected by laws and regulations in order to ensure an adequate availability and a good quality. Unfortunately, today there are no similar laws and regulations related to soil.

In Italy the main legislation on soil protection is the law 152/2006, mainly related to hydrogeological instability protection. The absence in the national legislative framework of an appropriate definition of soil creates problems in formulating laws able to properly protect it. The lack of a clear definition also affects soil consumption, generally confused with urban sprawl phenomenon.

Data from the Italian National Statistics Institute (ISTAT, 2013) show that the volume of authorized new buildings or the existing ones expansion remained constant over time, with a slight decrease for the period 2005-2006. It is estimated that over 200,000 people employed in building sector have lost their jobs and that more than 15,000 construction companies have closed, with an overall investments decrease in construction industry of 25.8% in the period 2008-2012 (ANCE, 2012).

Despite the large number of buildings realized, in Italy the topic of housing emergency is commonly discussed one. Considering the last national census (2011) the number of households increased by 54% compared to 1971.

The increasing incidence of divorce and immigration phenomena tends to reduce households dimension, with the average number of components that passes from 3.3 persons in 1971 to 2.4 in 2011. In 2011 there was an increase of 11.5% in the number of occupied housing compared to 2001. 72.1% of families own the house where they live, 18% rent a house and the remaining 9.9% of dwellings are used free of charge or as provision of service.

Apparently, the great housing offer seems to answer a real need dictated by socio-economic dynamics of the country. The emergency is evident observing the Ministry of Interior’s data, which highlight a growing number of evictions, 90% of which is the result of default in payments. This highlights a gap between housing supply and demand. Housing is considered as a safe investment due to the continuous increase in real estate value. Consequently investors increase their profit, while new houses remain inaccessible to the part of the population that actually needs it.

Decisive is the role of local authorities. In Italy every municipality has the possibility to determine the amount of land to be transformed on its territory, without controls at the regional scale able to determine the real needs of population. In addition, since 2004 with the law 331, municipalities have the opportunity to use up to 75% of income from urbanization costs for general expenses of administration. This encouraged municipal administrations, with great economic problems due to the huge reduction of public funds transferred from the central state, to use land as a bargaining chip in order to repair their finances.

The lack of specific regulations concerning soil consumption caused a huge increase of the phenomenon in Italy, at a significant speed. From 2008 to 2013 an average of 55 hectares of land per day have been consumed. While in 1950, consumed soil amounted to 8,100 km^2, equivalent to 2.7% of the national soil, in 2014 the consumed soil is approximately 21,000 km^2, 7.0% of the national soil. The phenomenon appears to be more significant in the north of Italy.

However, in recent decades central Italy has also significantly increased soil waterproofing speed, reducing the difference between the northern part of the country. In Southern Italy, the Apulia region has a high percentage of soil consumption and it is included amongst the five regions of Italy with a higher percentage. Basilicata region does not present critical situations, with a percentage of consumed soil equal to 5%. This value, however, becomes more alarming considering the very low population density of this region. Fortunately, in the past, tourism sector has not developed in the coastal area, consequently the Basilicata region has the lowest value of consumed land ranging between 300 and 1000 meters from where the shore line is measured, with only 3.1% of sealed soil. In this range the highest value is measured in the Abruzzo region, which has 26.8% of consumed land. In the range within 300 meters from the shoreline the Marche Region reached 40.7% of consumed soil (ISPRA, 2015).

Consequently, a legislation limiting and preventing further consumption of soil in Italy is indispensable. A law (2039) on land use containment and reuse of built soil is currently under discussion at the Italian Chamber of Deputies. The law allows soil consumption only in contexts where there are no possibilities of urbanized areas reuse. An important issue highlighted in the law is land use monitoring, required in order to define a complete and easily updateable framework of knowledge.

The definition of predefined thresholds of urbanization increasing, as happens in the German model, in the Italian context cannot ensure the overcoming of functional problems of a sprawling city, such as inefficiency of public services, over-consumption of energy and fuel, ecosystems fragmentation.

It is desirable that mere quantitative limitations are coupled with further control tools, able to monitor and guide the development of morphological land use changes and able to affect transport networks density and type. Consequently in analysing the phenomenon it is important to adopt a model able not only to quantitatively measure soil consumption , but also to highlight the spatial distribution of the phenomenon.

2. A Quantitative Model to Assess and Predict Land use Changes

This paper shows a model application for the analyses and time-space prediction of soil consumption, as an essential condition to define effective policies aimed at containing the phenomenon, knowing the actual soil use of a territory at two different time periods. Studying land use change means to analyse the variation in time of its use, more specifically to understand how much soil was sealed in the elapsed time between the first and the second land use survey.

Building an analysis and prediction model mainly means considering three main issues:

- it is necessary to identify changes occurred over time and understand factors that generated them;
- it is important to study the various influence factors and determine the rules that connect them to each other;
- it is possible to make predictions about future changes and their geographical location.

While the identification of changes may be the result of a simple visual comparison, subsequent phases require the use of a more scientific approach to identify correlations between the various factors of influence and make a prediction of future changes. In this work, in order to make predictions about future land use changes and build scenarios to support decision making, statistical algorithms have been used to analyse and simulate the variations of soil use or its coverage.

In last decades a lot of models have been proposed to analyse land use and land cover change (LUCC) (Romano and Zullo, 2013; Koomen, 2007; Perchinunno et al., 2012; Modica et al., 2012; Martellozzo, 2012; Nolè et al., 2015a; Nolè et al., 2014b; Cerreta and Poli, 2014; Murgante and Danese, 2011).

LUCC models are a useful support in the analysis of land use change causes and consequences, in order to fully understand the functioning of complex urban and territorial systems and to support the decision-making process (Verbug et al., 2004). Among them, a significant role is given to models based on cellular automata (CA).

A CA is defined as a discrete space consisting of cells, each of which is in a specific state, which can vary as a function of the current state and the one assumed by all the neighbouring cells, according to transition rules a priori defined (Von Neumann, 1996). Among the most popular models based on CA SLEUTH and DINAMICA models should be mentioned.

DINAMICA is a cellular automata model based on multi-temporal stochastic processes. In this model transition dynamics between different land use categories are calculated by probabilistic rules assessed in the neighbourhood of each cell in which the territory is decomposed. The model is constructed to reproduce land use changes shape and size, such as deforestation generated by several pressure factors. From a formal point of view, the model is based on the application of logistic-regression to identify areas most subject to each type of transition. The main input of this model is a landscape map, generally obtained through the classification of data derived from remote sensing. Maps of factors that are considered to have greater impact on land use dynamics are used with the landscape map. The result of the application of this model is a landscape map at a future time horizon and a map of the transition probabilities. DINAMICA was initially implemented for the analysis of landscape evolutionary dynamics of the Amazon, with particular reference to areas occupied by agricultural colonial funds smaller than 100 hectares (Soares-Filho et al., 2002).

Successfully applied in more than 66 cities and regions around the world (Chaudhuri and Clarke, 2013), SLEUTH model uses two land use maps correctly classified, adopted in calculating the transition matrix that highlights the occurred changes from class to class, and at least four urban maps, in order to represent a long time series of the characteristics of settlements growth, allowing a proper model calibration. A layer called excluded is used to represent all elements that oppose to urbanization phenomenon. Finally, slope and hillshade map are used to describe geomorphological characteristics of the study area (Clarke and Gaydos, 1998).

The model is based on four rules of settlement growth: diffusive growth, new spreading centre, organic growth and road influenced growth. Each phase is affected by the value assumed by five factors: dispersion coefficient, breed coefficient, spread coefficient, slope resistance factor and road gravity coefficient. A significant effort is to determine the correct value to be attributed to each of these factors. In fact, the calibration step of the model is particularly delicate, because of the high effort required in computational and time terms (Dietzel, and Clarke, 2004). Many problems have been associated with the application of this model over the years (Jantz and Goetz, 2005; Jantz et al., 2004). Among these, the tendency to consider more the board growth than dispersed settlements, and not high efficiency in identifying areas where it is most probable that urban growth will occur. It should be considered, also, the computational complexity of calibration step, which complicates model application through the use of raster data having high spatial resolution. Other models based on CA founded their calibration on data-driven methods, for example using neural networks (Li and Yeh, 2000).

The aim of this study is to propose a model which, on one side, is able to measure variations occurred in land use, and, therefore, to determine soil consumption, and, on the other side, is capable to predict future changes.

In order to overcome the computational complexity typical of other models based on cellular automata, a model of land use change based on cellular automata framework has been adopted, but driven by transition rules defined through a data-driven structure.

The simulation is based on two methods. *Joint information uncertainty* (Smith et al., 2002) has been adopted in estimating spatial relationships between variables.

Subsequently, *Weights of Evidence* (Smith et al., 2002) method has been adopted to determine a probability map. More in particular, a raster map has been produced where the value of each pixel is included in a scale ranging between 0 and 100, where the value indicates the conditional probability that a certain land use change occurs.

The model adopts three land use maps in raster format at different dates T0, T1 e T2 and the spatial variables, also in raster format, that geographically identify factors, such as constraints or planning regulations which contribute to influence soil transformations. The model has been applied two times: the first one in order to determine a calibration, the second in order to produce a simulation.

Model calibration aims to adequately define the relationship between spatial variables in order to produce simulation results coherent with actual land use changes. Maps at dates T0 and T1 are used as input in order to create a simulation at time T2. At this point it is possible to compare the simulation T2 with the actual land use at T2.

When the two maps are appreciably similar, the model will be properly calibrated, and it will be able to produce simulations which well describe actual land use changes. The simulation adopts the already calibrated model with maps at T1 and T2 dates in order to produce a land use at T3 time (Fig. 1).

Evaluating variables correlation, we suppose to detect two politomic variables, able to assume a number of values greater than two, in a sample of n subjects.

A double-entry table containing non-negative numbers can represent data. This is called a contingency table with $(m-1)(p-1)$ degrees of freedom (Fig. 2). It is a table with the joint distribution of two variables. More in particular, rows in the table identify n values of X variable, while columns identify p values of Y variable. The generic cell n_{ij} represents the absolute joint frequency, i.e. the number of statistical units in the sample that joint a feature associated with mode x_i of the i-th row and a feature associated with mode y_j in the j-th column. The total of each row represents the frequency with which the mode of the first variable X was observed. Joint information uncertainty is part of entropy measures (Bonham-Carter, 1994). These are calculated by the analysis of contingency table, and can be used to measure the association between two variables. Assuming to transform n_{ij} values in proportion to the area, dividing each element by the total n:

$$p_{ij} = \frac{n_{ij}}{n}$$

and also defining:

$$p_i = \frac{n_i}{n}; p_j = \frac{n_j}{n}$$

entropy measures can be defined using the value of p_{ij} as probability estimation.

This value is dimensionless, and it can be then compared to measurements with Pearson chi-square, with the advantage of not having dependencies on measurement units.

Considering map A and map B and considering the contingency table as known,

A and B entropies are defined as:

$$H(A) = -\sum_{j=1}^{m} p_j ln p_j$$

$$H(B) = -\sum_{i=1}^{m} p_i ln p_i$$

where ln indicates the natural logarithm. The joint entropy of two maps combination will be defined as

$$H(A, B) = -\sum_{i=1}^{m}\sum_{j=1}^{m} p_{ij} ln p_{ij}$$

The joint information uncertainty is used as strength measure of the association, and it is defined as

$$U(A, B) = 2\left[\frac{H(A) + H(B) - H(A, B)}{H(A) + H(B)}\right]$$

always ranging between 0 and 1.

When the two maps, and therefore the variables, are completely independent of each other, we will have $H(A, B) = H(A) + H(B)$ and $U(A, B) = 0$, in the case of perfect dependence we will have $H(A, B) = H(A) = H(B) = 1$ and $U(A, B) = 1$.

Once determined the correlation between variables, the conditional probability is quantified by Weights of Evidence method (WoE), which belongs to the *Information Theory* statistics. WoE is based on Bayes' theorem, which states that given a predisposing factor B, divided into thematic classes, and an event s, the conditional probability that the event s occurs in the presence of the i-th class B_i is equal to:

$$P(s|B_i) = \frac{\{P(B_i|s) \times P(s)\}}{P(B_i)}$$

where:

- $P(B_i|s)$ is the conditional probability of B_i given the event s;
- $P(s)$ is the a priori probability that event s, also called source, occurs in the study area (AS);
- $P(B_i)$ is the probability of finding class B_i in the study area (AS).

The conditional probability that the event s will not occur in correspondence to the class B_i is instead defined by the relation:

$$P(s|B_i\hat{}) = \frac{\{P(B_i\hat{}|s) \times P(s)\}}{P(B_i)}$$

where:

$P(s|B_i\hat{})$ is the conditional probability of not having the class B_i assigned to event s;
$P(s)$ is the a priori probability that event s occurs in the study area (AS);
$P(B_i\hat{})$ is the a priori probability that class B_i is not present in the study area (AS).

In operative terms, it is possible to calculate:

$$P(s) = (\text{area } s)/(\text{area } AS)$$

$$P(B_i) = (\text{area } B_i)/(\text{area } AS)$$

$$P(B_i\hat{}) = (\text{area } B_i\hat{})/(\text{area } AS)$$

$$P(s|B_i) = (\text{area } s\_B_i/\text{area}B_i)/P(B_i)$$

$$P(B_i|s) = (\text{area } s\_B_i/\text{area}B_i)/P(s)$$

$$P(s|B_i\hat{}) = (\text{area } s\_B_i\hat{}/\text{area}B_i\hat{})/P(B_i\hat{})$$

$$P(B_i\hat{}|s) = (\text{area } s\_B_i\hat{}/\text{area}B_i\hat{})/P(s)$$

From a purely mathematical point of view, it may be useful to express the probability in terms of Odds. This is the ratio of probability occurrence of an event and probability that this event does not happen. In this case the two previous equations can be rewritten in the form:

$$O(s|B_i) = \frac{O(B_i|s)}{O(B_i)} O(s)$$

$$O(s|B_i\hat{}) = \frac{O(B_i\hat{}|s)}{O(B_i\hat{})} O(s)$$

From these we can calculate odds natural logarithm obtaining:

$$\ln O(s|B_i) = W^+_{B_i} + \ln O(s)$$

$$\ln O(s|B_i\hat{}) = W^-_{B_i} + \ln O(s)$$

where W^+ is the positive weighted value that should be assigned when i-th class of factor B is present, while W^- is the negative weighted value assigned when i-th class of factor B is absent. The two weighted values can be obtained according to the expressions:

$$W^+_{B_i} = \ln \frac{P(B_i|s)}{P(B_i|s\hat{})}$$

$$W^-_{B_i} = \ln \frac{P(B_i\hat{}|s)}{P(B_i\hat{}|s\hat{})}$$

W^+ can be seen as the ratio between the probability of finding a thematic class in which the event occurred and the probability of finding the same class in the absence of the considered event; while W^- can be seen as the ratio of the probability of not finding a thematic class in which the event occurred and the probability of not finding the same class in an area where the considered event is not present.

It is possible to observe that the greater the weighted value of the considered class in predicting the event under investigation will be, the greater the value W^+ will be, and similarly the lower the weighted value of the considered class in predicting the event under investigation will be, the greater the value W^- will be.

The difference between positive weighted-value and negative weighted-value is defined as contrast:

$$C = W^+ - W^-$$

and it is an effective measure of the correlation between the analysed thematic class and the considered events represented on a cartographic base.

A thematic class that produces null contrast values is not significant for analysis purposes, while a contrast positive value indicates a positive correlation of the thematic class compared to the examined events, and negative values suggest that the spatial distribution of thematic classes is independent in relation to the considered phenomena. In other words, the more the occurrence of an event within a thematic class is greater than its random distribution, the more W^+ and W^- will assume positive and negative values, respectively. Therefore, in case there is a positive spatial correlation, the number of events within the thematic class is higher than those randomly obtained, and vice versa for a negative spatial correlation in the considered thematic class the number of events is less than those due to a random distribution.

The Weights of Evidence method is particularly useful in land use changes prediction, because it effectively interprets relationships between these variations and the adopted spatial variables.

The entire model was implemented using free software, such as R-Statistics and the open-source software QGis. In this way it was possible on the one hand to constrain the execution of the CA model to the typical raster analysis in GIS environment, on the other hand to develop a statistical knowledge of the space variables values used in simulations. The GIS software was used for raster maps construction related to each space variable, while R-Statistics was used to implement the script able to calculate values of WoE and JIC to associate to each cell of various considered factors.

3. The Case Study

The proposed model has been applied to a real case study. The study area is Pisticci Municipality in Basilicata region (Southern Italy) (Fig. 3). Basilicata is a region with low population density (575 505 inhabitants distributed on 9,992 km^2, corresponding to 57.5 inhabitants/km^2) that, partly because of bad policy, partly due to a lack of large private investors, in past decades has not been able to exploit its territory with high landscape values to develop tourism. Pisticci municipality is a significant example.

Third centre of Basilicata for inhabitant number, Pisticci is located in an area between Cavone and Basento rivers. Two important highways, S.S. Basentana and S.S. Jonica, also cross the territory (Fig. 4). Ridges and uplands characterize the northern part of the municipality, while the area close to Ionian Sea has mostly a flat conformation.

The coastal area, characterized by strong tourism pressure, constitutes one of the most relevant areas to be analysed in the field of land use changes. The municipal area is therefore characterized by great diversity, due to the varied morphology, and has led in earlier times to locate the settlement along the main ridge. Only later, in the late twentieth century, building development has moved downstream, and in recent times has involved the coast. In addition to the main centre, other important settlements, as Marconia and Tinchi hamlets, have been developed in the valley, while small rural villages and tourist sites characterize the coast. In the area closest to the historical settlement of Pisticci, large areas used for natural pasture are measured. These areas are the steepest in the whole municipality and are characterized by arid and clay soil, mostly not irrigated. These characteristics define the Calanchi (geological formations determined by erosion on clay soils), which contribute to uniquely characterize the landscape of the area. Moving towards Tinchi and Marconia, it is immediately noticeable how the original vocation of these settlements was agriculture, and still today the soil surrounding the extra-urban area of these two centres is characterized by the presence of crops, irrigated or not.

Data is measured through surveys carried out on the map at 1:25,000 scale of 1952 by Italian Military Geographic Institute (IGM), on IGM maps at 1:50,000 of 1972, and on ortho-photos from 1982, 1989, 1997, 2000 and 2006, at 1:10000 scale, available in Web Map Service (WMS) format on Italian National Geoportal (www.pcn.minambiente.it/). The increase of built-up areas at the various dates firstly coincides with the development of the two settlements of Tinchi and Marconia, then with housing development of the coastal zone (Table 1).

In a less intense but steadily process over time, an increase of buildings number within extra-urban area is observed, especially in correspondence of main transport infrastructures.

The case of Pisticci is a significant case in the context of the Basilicata Region, because it is one of the most populated municipalities, and it is in part supported by agricultural economy, like a great part of municipalities included in this coastal zone, in part by tourism. Consequently, soils, especially in the coastal area, are constantly suspended between agricultural and urban uses. Moreover, the presence in addition to the historical settlement of other two centres of significant dimensions means that there are three urban contexts, and therefore three components capable to change the positional rent in surrounding soils. The application of the model is limited for the lack of basic spatial information, which is typical in a great part of Italy. Unable to use a time series data on the actual land use, we decided to use only data on built-up areas. The application is therefore designed to measure sprawl occurred in the area and to estimate the dimension that this phenomenon can have in the future. Obviously, in this way it is not possible to measure total soil consumption, but still it is possible to identify the extent of the main component of the phenomenon. Table 2 shows input data used for model implementation.

All spatial variables used in model execution have been represented through raster maps classified and discretized, because it is not possible to calculate WoE and JIC for continuous variables, as mentioned above. For each class of values assumed from raster cells WoE was calculated: a greater class transformation from not built to built is associated with the growth of such value. The absence of effective planning tools at wider scale in the area creates problems in identifying the main factors affecting land use transitions. Analysis of Digital Terrain Model allowed the construction of slope and exposure maps. Slope has been reclassified in order to distinguish areas with very low, low, medium, high and very high steepness; exposure has been reclassified in north, south, east, west, south-east, south-west, north-east, north-west. Slope classification and subsequent WoE calculation for each class highlighted a resistance to development in higher slope areas. Similarly, a lower transformation of zones exposed to north, compared to areas exposed to south, south-east, south-west was evident. Further resistance to soils transformation from unbuilt to built is determined by landscape constraints. In this case, raster data associated to each constraint are Boolean with 1 or 0 values in each cell. The impact evaluated for new development areas identified by planning tools at urban scale is different. In this case it is evident that, independently on what happened with constraints, these tools are catalysts for urban transformations.

Density of buildings affects the probability of transformation of a cell from unbuilt to built: Woe showed a greater densification tendency in correspondence of more densified areas and close to the main road

Table 1
Quantity of built-up areas [ha] measured at different times.

	1956	1972	1982	1989	1997	2000	2006
Unbuilt [ha]	23088	23077	23058	23018	23010	23007	23005
Built [ha]	28	39	58	98	106	109	111

Table 2
Input data used for model implementation.

Category	Variable
Built-up areas	Built-up areas in 1956
	Built-up areas in 1982
	Built-up areas in 1989
	Built-up areas in 2006
Geomorphological system	Slope
	Sun exposure
Environmental system	Maritime constraint
	Hydrogeological restrictions
	Forestry constraint
	Areas subjected to environmental regeneration
	Landscape plan (mouth of Basento river)
	Not transformable areas
Settlement system	Urban Implementation Plans and Shores Plan
	Building density
Relational system	Distance from the main road

network, confirming that transport networks are among the main attractors of urban sprawl phenomena.

In model execution, during the calibration phase, maps of built-up areas at T_0 time (1956) and at T_1 time (1982) have been used. In this way, the simulation has been performed using Weights of Evidence, getting built-up areas map in 2006 as output. This simulation has been compared with the reference map at T_2 time, i.e. actual built-up areas map in 2006 and when the error has been considered insignificant the simulation phase has been implemented. In the second phase built up areas in 1989 and 2006 have been adopted as input data, running again the WoE with the same previously calculated contrast parameters, in order to obtain a simulation of built-up areas in 2024 (Fig. 5).

4. Data Processing and Results

Simulation results should be analysed under two different profiles: quantitative and positional ones (Fig. 6). Initial assessments should refer to quantitative aspects, purely comparing numerical terms of the amount of built-up areas provided by the simulation to those measured in 2012, without considering the geographical distribution of these quantities at this moment.

This comparison can be significant when comprehensively analysing the current situation of the Pisticci Municipality in terms of demography and building development. Observing the comparison between population and built-up areas (Fig. 7), it is very evident that large building production generated in twenty years (between 1991 and 2011) is far from being supported by an actual demand increase by resident population, which is in slight decrease. Observing the comparison between households and number of dwellings, it is clear that growth in number of available dwellings has occurred at a rate much higher than growth in number of households. All comparisons carried out are exclusively based on resident population data, not taking into account how the economy of the Pisticci municipality a development in the tourism field in the last twenty years, which consequently produced an increase of housing demand. The demographic phenomena related to tourism, however, cannot justify the high soil consumption measured, and especially cannot justify the increase in number of buildings in areas distant from the coast. Moreover, simulation results show that the already existing trend is expected to continue in next years. In order to highlight this aspect, it is possible to compare simulation results for 2024 to data related to built-up areas actually present over the years. Assuming that the population will continue to follow the trend registered in the period 1991-2011, it is possible to observe a decrease of the population from 17361 to 16761 inhabitants, while there is a further increase of hectares of consumed land.

Consequently, if policy makers will not intervene in a drastic way to limit this housing phenomenon, urban sprawl will continue even in the next decade, despite there is not a significant demand increase.

Analysing simulation results from a positional point of view, geographical location of future buildings is very satisfactory. On the output map, contributions of different spatial variables can be read with clarity.

New buildings are never included on constrained areas or on soils where it is not possible to build. Instead, they are very dense in correspondence of settlements, thickening built-up areas located along the road connecting the historic part of Pisticci with the hamlets of Tinchi and Marconia. Data shown in Table 3 include also edifications occurred within urban areas according to planning documents. However, although this rate is due to planned changes and therefore not strictly included in sprawl phenomenon, these changes have also produced soil consumption. In Tinchi, the amount of new built-up areas realized since post-World War II up to 1982 was very high (4,43 hectares). In the same period the amount of built-up areas throughout the whole municipal area was 30 hectares. In other words, 14.76% of edifications realized between 1956 and 1982 were concentrated in Tinchi. The percentage is even higher considering that Marconia has been developed in

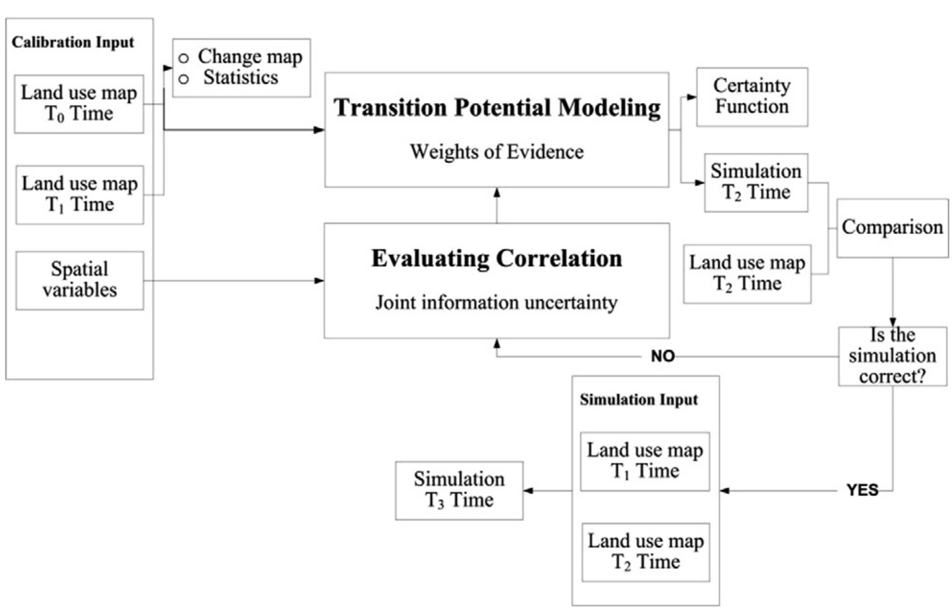

Fig. 1. The scheme shows the sequence of the different phases of model calibration and simulation.

	y_1	y_2	$\cdot\cdot$	y_j	$\cdot\cdot$	y_p	
x_1	n_{11}	n_{12}	$\cdot\cdot$	n_{1j}	$\cdot\cdot$	n_{1p}	$n_{1\cdot}$
x_2	n_{21}	n_{22}	$\cdot\cdot$	n_{2j}	$\cdot\cdot$	n_{2p}	$n_{2\cdot}$
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	
x_i	n_{i1}	n_{i2}	$\cdot\cdot$	n_{ij}	$\cdot\cdot$	n_{ip}	$n_{i\cdot}$
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	
x_k	n_{k1}	n_{k2}	$\cdot\cdot$	n_{kj}	$\cdot\cdot$	n_{kp}	$n_{k\cdot}$
$\vdots$	$\vdots$	$\vdots$		$\vdots$		$\vdots$	
x_m	n_{m1}	n_{m2}	$\cdot\cdot$	n_{mj}	$\cdot\cdot$	n_{mp}	$n_{m\cdot}$
	$n_{\cdot 1}$	$n_{\cdot 2}$	$\cdot\cdot$	$n_{\cdot j}$	$\cdot\cdot$	$n_{\cdot p}$	n

Fig. 2. Contingency table.

the same period, determining great part of the 30 hectares consumed. Most of the 30 hectares not built in Marconia, therefore, were built in Tinchi.

The comparison between built-up areas measured in the period 1991-2012 and resident population data provided by ISTAT (Italian Institute for Statistics) shows that the rapid growth of built-up areas is accompanied, instead, by a slight fluctuation of resident population. In the period 1991-2001 a slight increase occurred, while in the next decade a small reduction took place, with 26 residents less than 1991 in 2011. The simulation considers that in 2024 Tinchi will have total built-up areas equal to 16.15 hectares. The simulation map (Fig. 8) shows as such an increase will be homogeneously distributed between Tinchi and its surrounding areas. In both situations, however, the simulation provides a concentration of new buildings in proximity of already built areas, defining a densification trend towards existing settlements. The development of Marconia from 1956 has been continuous (Fig. 9). In 1956 the settlement was mainly agricultural, with 1.19 hectares built, which became 8.91 in 1982. The largest increase, however, occurred in the eighties when 17.48 hectares were built areas. In only seven years, therefore, built-up areas grew with the impressive speed of 2.49 hectares per year. Building has also continued during the nineties, and still continues nowadays, although at slower rates. In 2006 there were 1.71 hectares more than in 1989, and in 2012 2.49 ha more than in 2006. It is possible to make two considerations. The first one is that rate of construction in the late nineties and in the early years of the current decade was less than that calculated in the previous decade.

The second one is that, in contrast with the national trend, a new acceleration in building took place from 2006 up to 2012. The case of Marconia is significant because for the first time an increase of built-up areas is accompanied by an increase of resident population. This is mainly due to migratory movements within the municipality, from the historical settlement of Pisticci to Marconia. Analysing 2001-2011 decade, it is possible to note that although the population is still growing, the increase is less than in the previous decade, while built-up areas increased with a rate greater than the period 1991-2001. The last situation analysed is the territory closest to the coast. More specifically, what occurred to soils located at a maximum distance of 3 km from the shore line will be evaluated. Building activities in this strip are mainly due to the desire to create an environment suitable for the reception of tourists during the summer season (Fig. 10). Therefore, in this case it is not possible to compare sprawl with data on resident population, because such data do not consider people who spend only short periods in the municipality. Land use changes in the coastal strip of Pisticci municipality are quite alarming. In 1989, there were 3.95 hectares of built-up areas, which became 7.94 in 2006. In 2012, the datum is almost doubled up to 15.68 hectares of built-up areas. These increases are mostly due to the realization and completion of tourist villages. The increase of buildings scattered along the main roads in the areas should be considered, also.

Also in this case, the simulation accounts for the considerable increase in building speed in the period 2006-2012. The prediction of additional 7.01 hectares of new built-up areas from 2012 until 2024 can represent a threat.

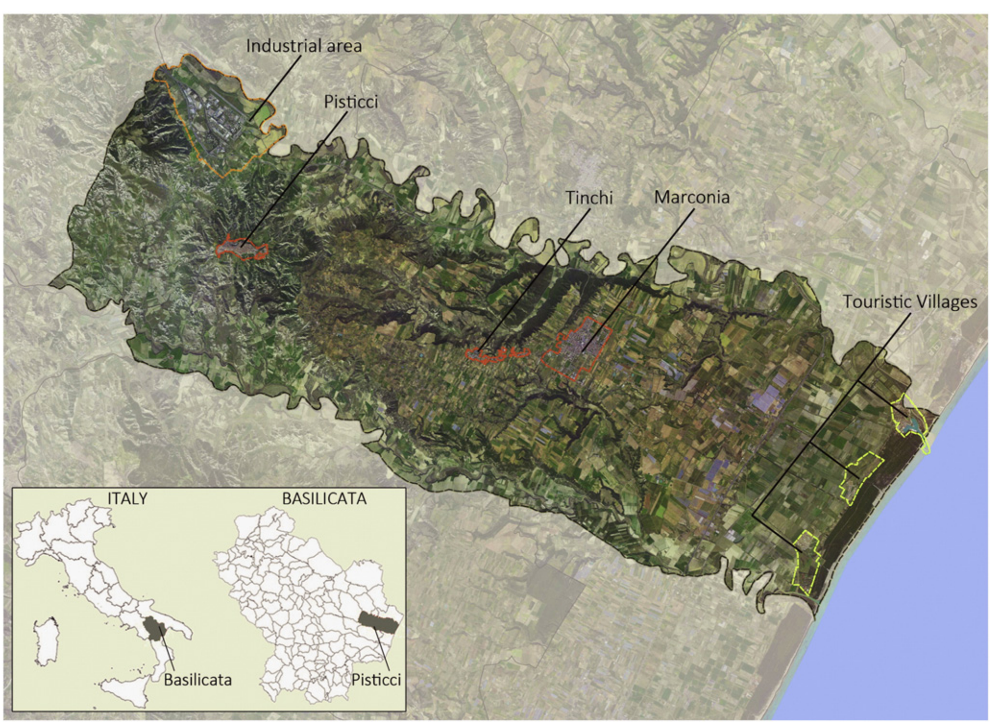

Fig. 3. Location of Study area.

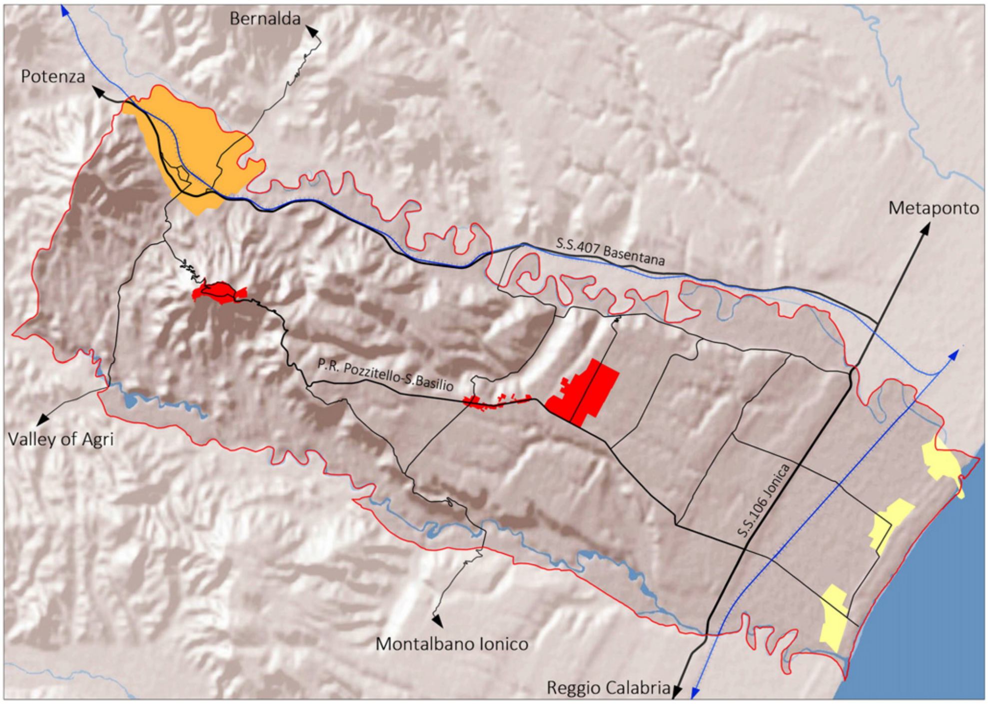

Fig. 4. Main axes of road network (in black) and railways (in blue) in the municipality of Pisticci; the urban areas of Pisticci, Tinchi and Marconia are highlighted in red, the industrial area in orange; the areas destined to construction of tourist resorts in light yellow.

San Leonardo, a place located east of the historical settlement of Pisticci, is extended in parallel to the axis of the Provincial Road Pozzitello-San Basilio. Analysing collected data and considering buildings at 1956, it is possible to observe that despite the location does not fall in the flattest part of the municipality, scattered settlements have exclusively an agricultural character. Only in the following years a massive increase in residential building occurred, probably attracted by the proximity to the provincial road, connecting Pisticci to Marconia and Tinchi, and by the location of a football field (Fig. 11). Great part of land use changes have been registered in the 80's of 1900. There was a transition from 1.39 hectares measured in 1982 to 3.48 hectares measured in 1989. In other words, considering the 4,38 hectares built in 2006, more or less fifty percent of them, 2.9 hectares, have been realized during the 80's. It is very strange that these changes occurred when the Plan has been already approved. The simulation collected in this area because of the proximity to the road was subject to a high probability of transformations. In fact, considering new built-up areas provided by the simulation, 7.3 hectares are geographically distributed in S. Leonardo.

Fontana Terrupo unlike the situations presented above, is not crossed or bordered by a major connector road. Even in this case, looking at the evolution of the phenomenon at different times it is

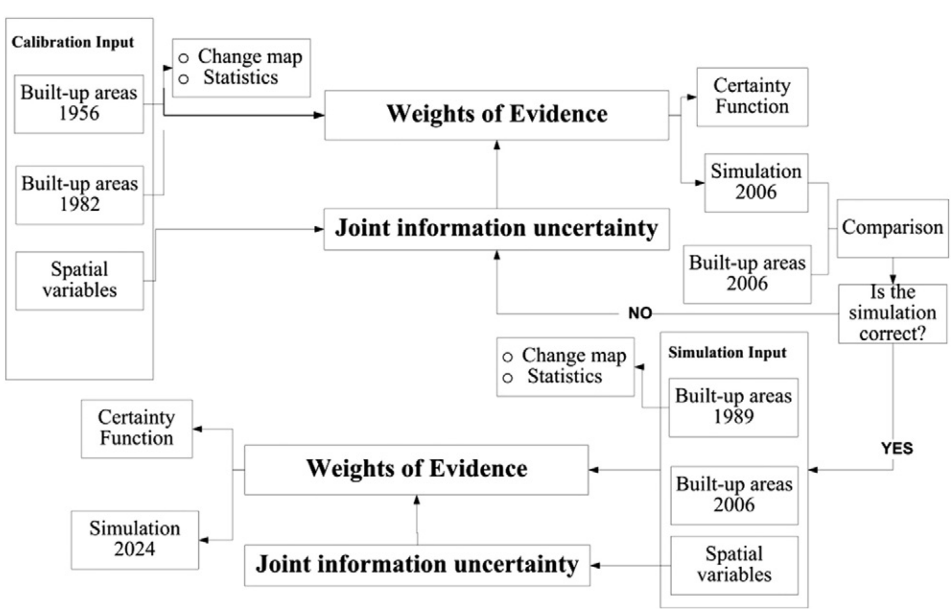

Fig. 5. The scheme shows the sequence of the different phases for the calibration and simulation of the model concerning the application to Pisticci municipality.

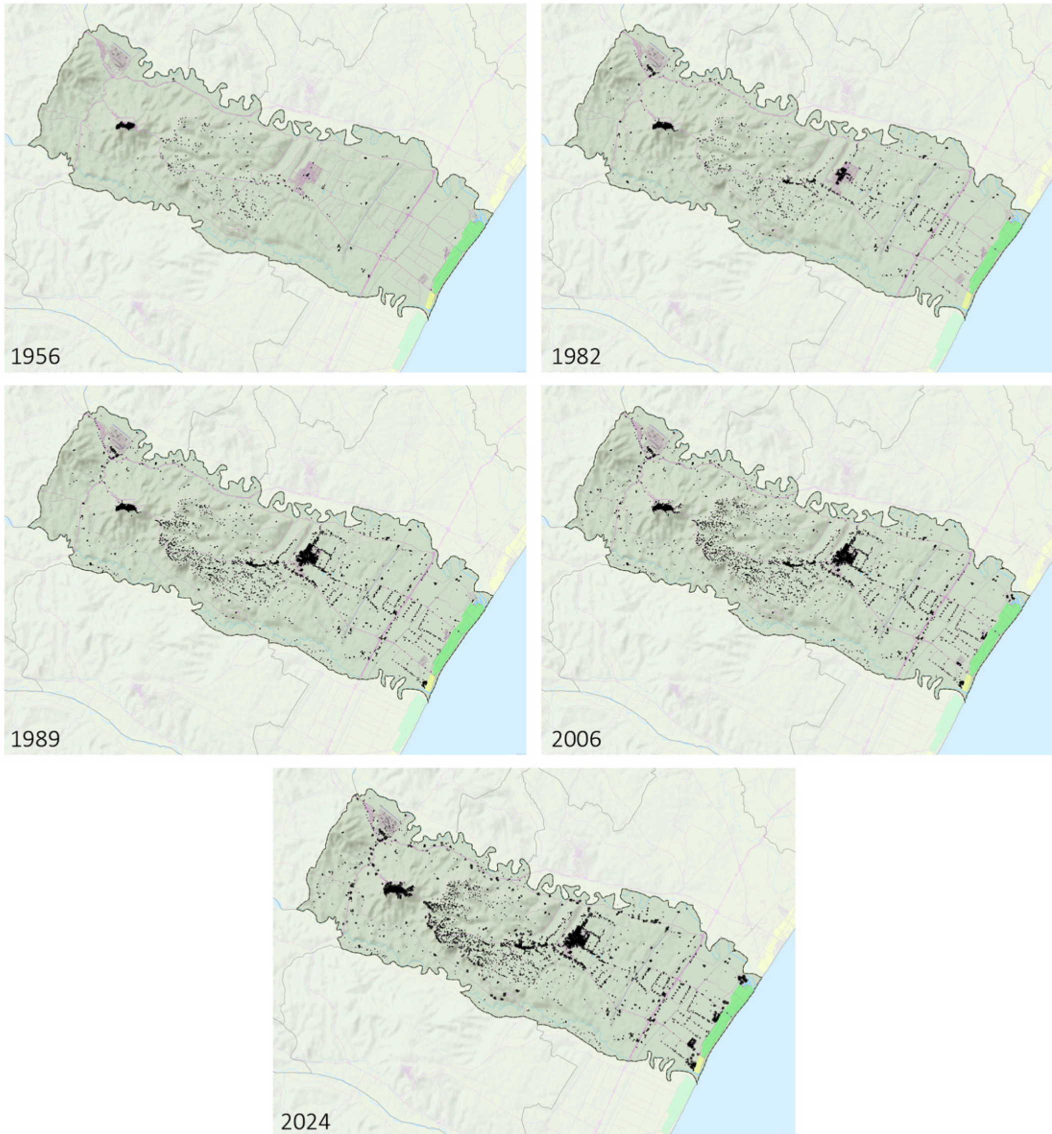

Fig. 6. From top to bottom, from right to left: the images show built-up areas within Pisticci Municipality in black, in 1956, 1982, 1989, 2006, respectively and in simulation for 2024.

possible to observe a constant growth in building activities. From a quantitative comparison, in 1956 there were 0.92 hectares built, which can be assumed attributable to agricultural use, in 1982 there was a small increase of 1.03 hectares. The great edification in this area is more recent: in 1980's built-up areas essentially doubled, with an increase of 1,1 hectares (Fig. 12).

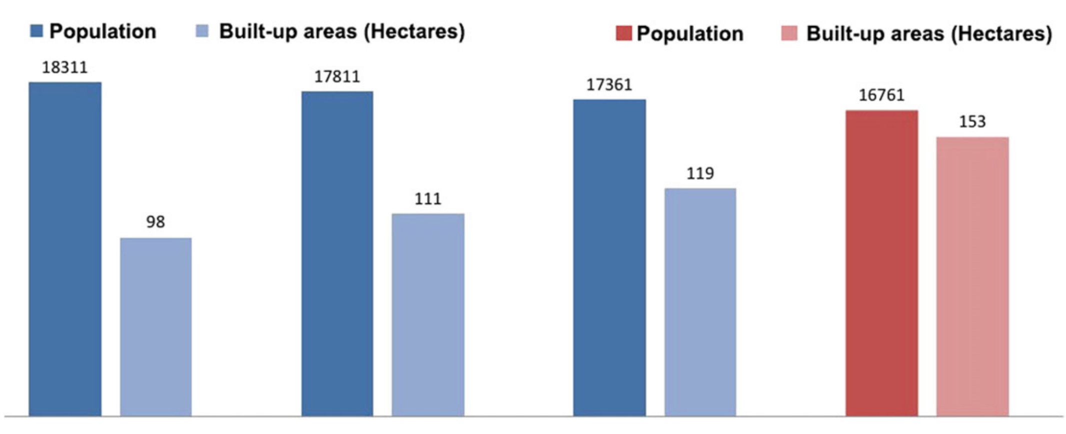

Fig. 7. Comparison between population and Built-up areas (Hectares) from 1991 to 2024.

Table 3
Quantity of built-up areas [ha] measured at different times.

	1956	1982	1989	2006	2012	Δ 56-12	Δ 12-24	2024
Pisticci Municipality	28	58	98	111	125	97	28	153
Tinchi	1.62	6.05	9.06	9.73	10.43	8.81	5.72	16.15
Marconia	1.19	8.91	26.39	28.10	30.59	29.4	7.10	37.69
F. Terrupo	0.95	1.03	2.04	3.06	3.27	2.32	0.40	3.67
S. Leonardo	1.32	1.39	3.48	4.38	4.82	3.50	1.24	6.06
Coastal area	0.14	0.85	3.95	7.94	15.68	15.54	7.01	22.69
Marconia	1.19	8.91	26.39	28.10	30.59	29.4	7.10	37.69

5. Discussion

The case study is suitable to many interpretations. First, the tendency of coastline overbuilding should be discussed: it occurred in recent decades and according to the simulation carried out, it will continue until 2024.

The increase in built-up land in coastal areas can be compared to what occurred along the Adriatic Sea coast of Italy since early seventies of 1900. In this period the development of tourist sector produced a huge soil consumption along the Adriatic coast from North to South indifferently (Romano and Zullo, 2014). As already mentioned, Basilicata region is not historically part of the main Italian tourist destinations. This trend changed in recent years, as highlighted in the case of Pisticci. Together with the development of tourism an excessive building up activity is taking place. The hope is that after what happened along the Adriatic coast and following the alarming results of many researches, including the present one, policy-makers may be encouraged to pursue sustainable tourism development (Romano and Zullo, 2013).

Nevertheless, the real anomaly emerging from the simulation results is the phenomenon of spontaneous and unregulated construction occurring mainly along two major roads. The first one, SP 154 road, connects Pisticci to Bernalda municipality, going north and to Montalbano Jonico, Policoro and Tursi municipalities, going south . The second one, SP-Pozzitello San Basilio, instead, has a key role within the municipal area because it connects the historical part of Pisticci to the more recent settlement of Marconia. It is not a coincidence that a significant new urbanization process occurred in recent years just at the intersection of these two major road infrastructures, partially planned (such as in the case of Tinchi settlement). This urban sprawl phenomenon is not justified, as mentioned earlier, by the most recent demographic trends in Pisticci.

The case of Pisticci Municipality is a particularly complex situation in the evaluation of land use dynamics. Considering the objective limitations to a further development of the main municipality centre (very high slope and frequent landslides), urban growth of the two secondary centres is observed, despite a structural and irreversible decrease trend in total town population.

This phenomenon is clearly linked to a population mobility in the area that tends to move towards residential areas with a greater supply of zones suitable for new neighbourhoods, better conditions of accessibility and employment opportunities related to the presence of services (e.g. the hospital in Tinchi).

The over-sizing of settlement offer in secondary centres and the lack of an integration and a functional complementarity strategy between

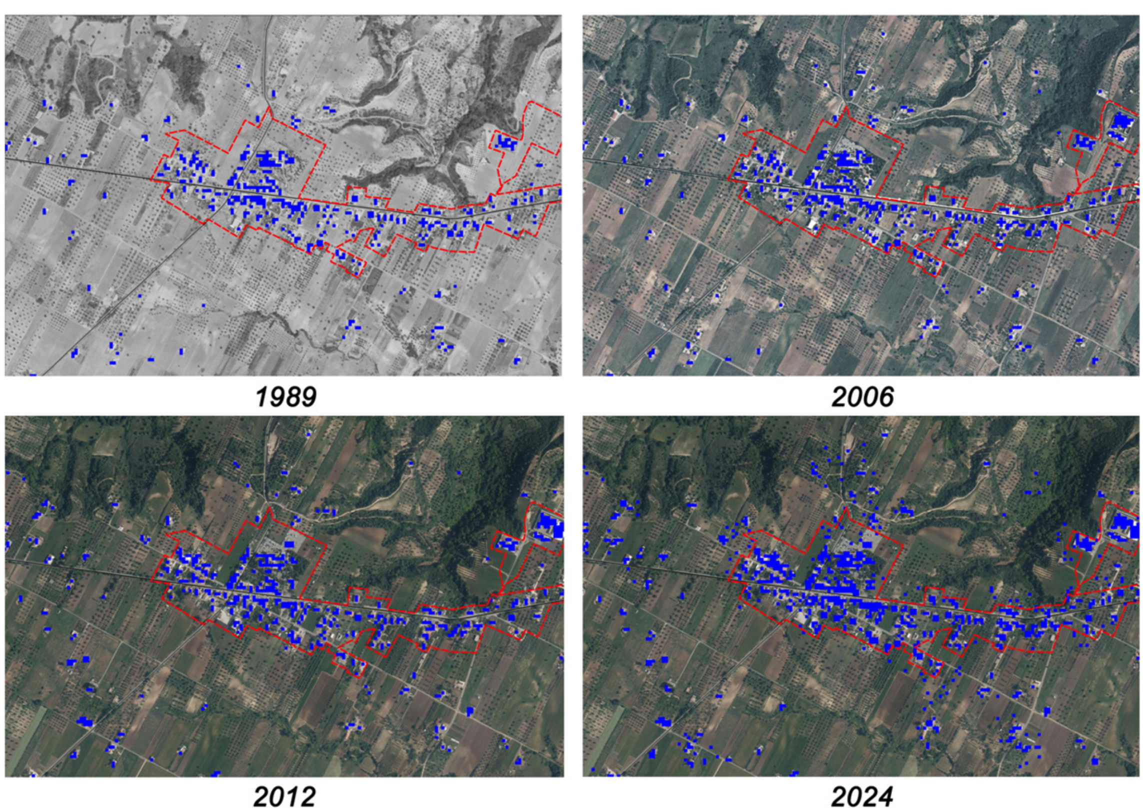

Fig. 8. The hamlet of Tinchi, highlighted by the red dashed line; blue pixels identify buildings at different dates.

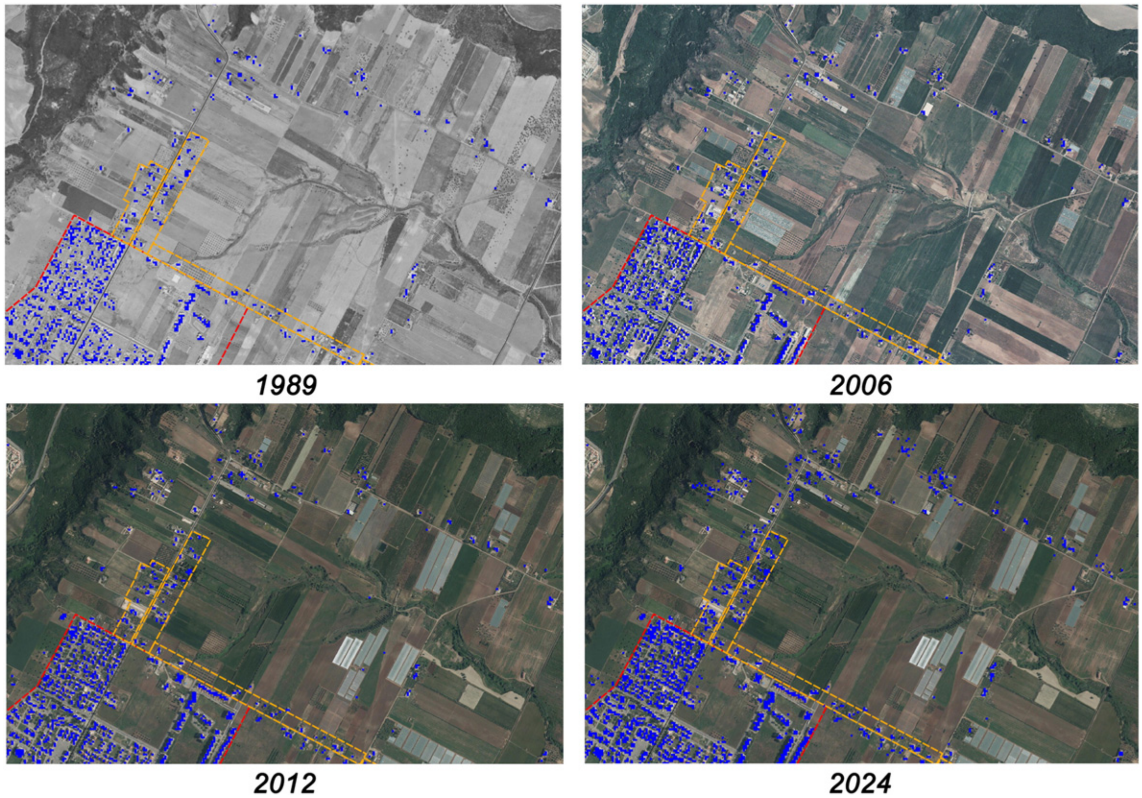

Fig. 9. The hamlet of Marconia, highlighted by the red dashed line; blue pixels identify buildings at different dates.

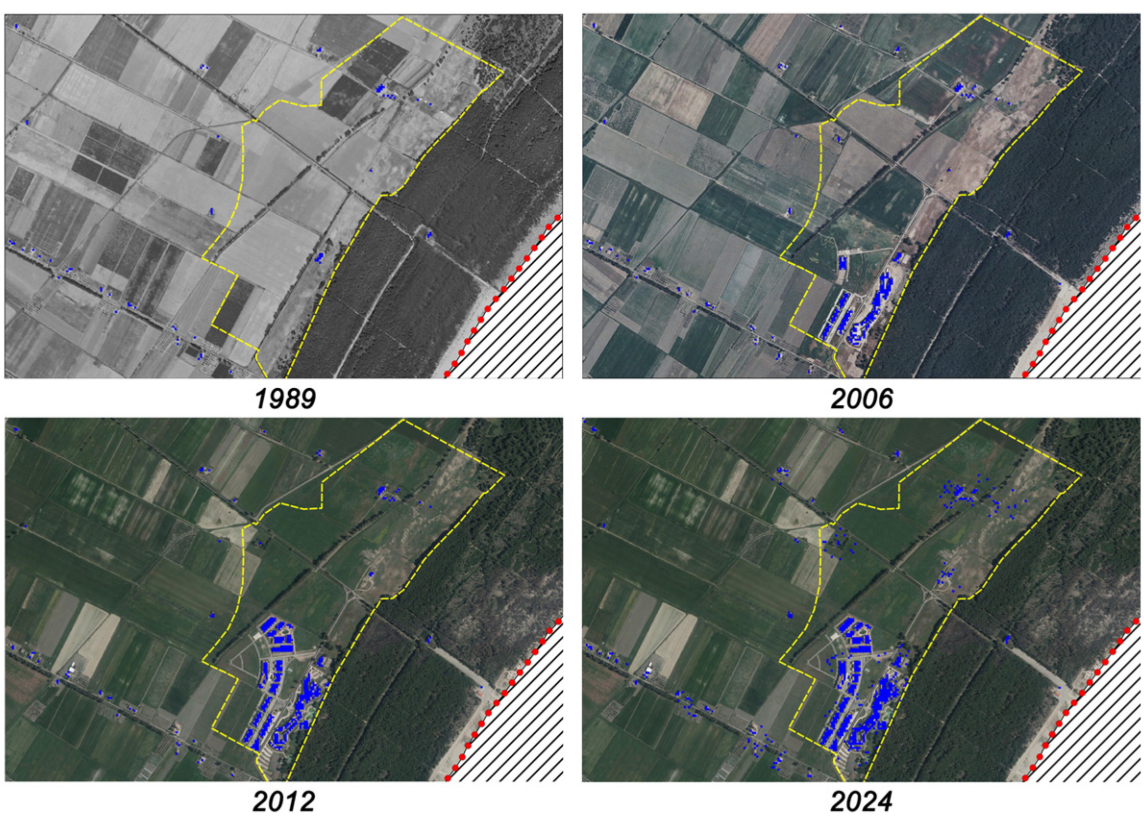

Fig. 10. An example of tourist village, highlighted by the yellow dashed line; blue pixels identify buildings at different dates.

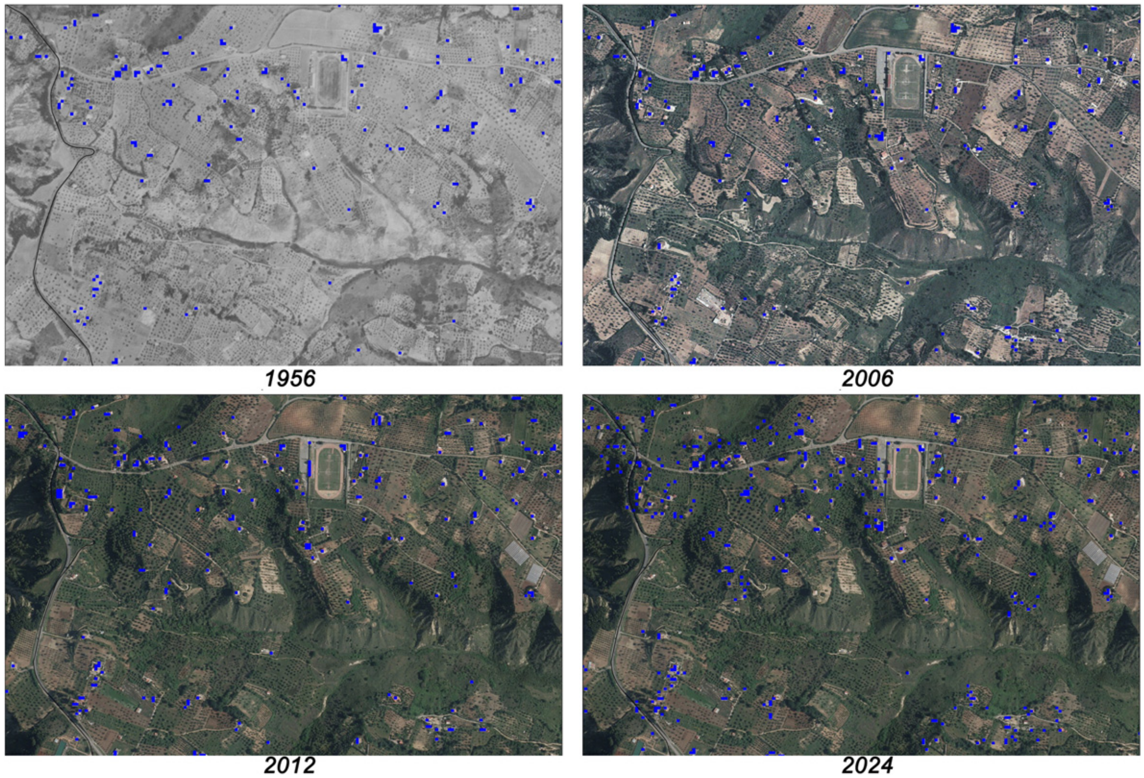

Fig. 11. San Leonardo; blue pixels identify buildings at different dates.

different settlements favoured the spontaneity of such a phenomenon, with consequent under-utilization of existing buildings, further soil consumption and extemporaneous supply of programming services.

A lack of planning regulations in rural areas (Landscape Plan under the Law 431/85 approved in 1986 is a no more adequate tool) and the governance failure of new settlements demand favoured very serious phenomena of urban sprawl along the main road connection between

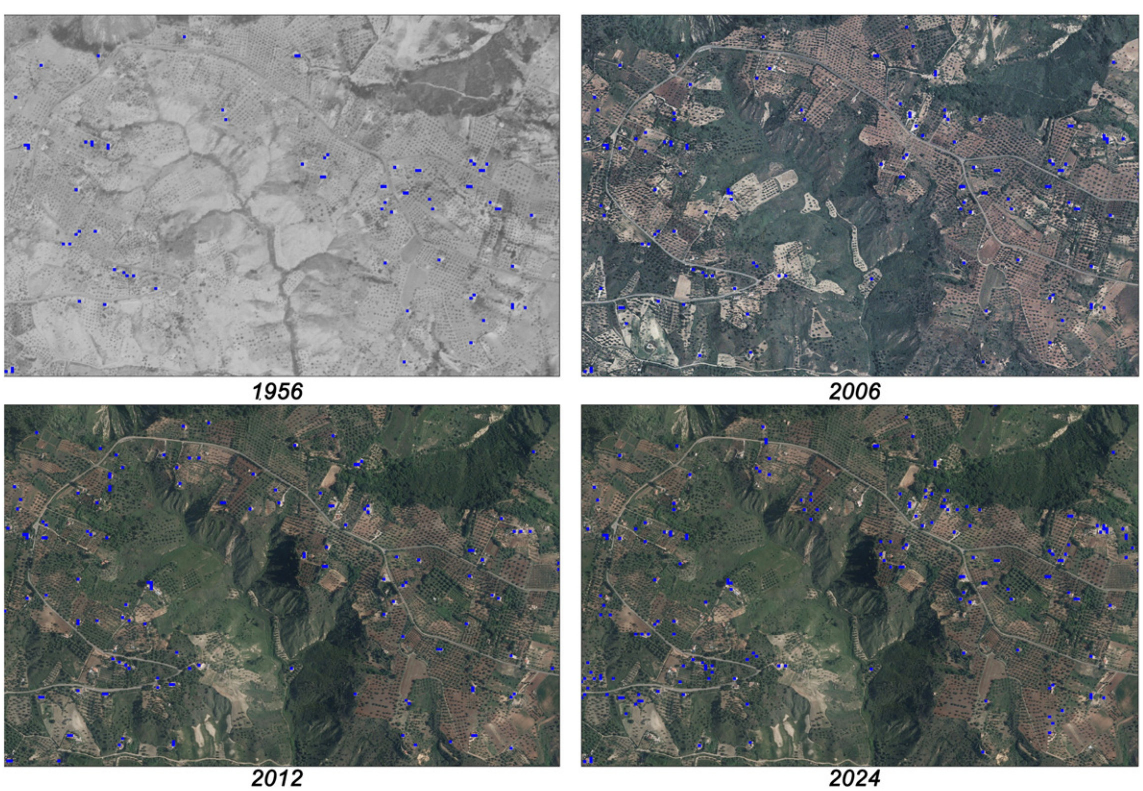

Fig. 12. Fontana Terrupo; blue pixels identify buildings at different dates.

the three principal centres. This phenomenon, if not controlled, is destined to further develop.

It is fundamental to undertake to two actions. Basilicata Region has to conclude the process of new Landscape Plan approval and particular attention should be paid to the opportunities offered by new Common Agricultural Policy for the period 2014 to 2020.

In general, extra-urban territory is now acquiring a clear multifunctional connotation as an essential context for biodiversity conservation, a place dedicated to agricultural and forestry activities, but also a place for residential settlements, small industrial, artisan, commercial and tertiary activities.

Rural areas are the place of agricultural and forestry activities, of natural and landscapes emergencies to preserve and promote. At the same time a place where, in the interests of maximum preservation of the common good, relevant processes of economic and functional innovation can be realized, generated by the creation of new economic activities and new social structures. These new features assigned to rural areas have to be coupled with a proper governance of urban sprawl phenomena, in order to avoid environmental damage, unjustified waste of territory and an increase of transport costs. In the case of Pisticci, it is necessary to implement new policies to protect and valorise the peri-urban and rural areas, paying particular attention to hydro-geological risk which affects part of the settlements. Coastal tourist resorts represent an important aspect: the most significant soil consumption phenomena take place along the coastline there are.

Also in this case, the lack of an integrated strategy for territorial development for the whole coastal area led to a condition of conflicts between different land uses that, in the case of Pisticci, is particularly significant. Policies aimed at reducing soil consumption should steer the development of tourist facilities towards more intensive models. Up to nowadays extensive models have been realized with the construction of tourist villages mainly based on second houses used only for summer vacations. Furthermore, the need to ensure tourist accommodations could be satisfied with the recovery of the historical part of Pisticci and the other centres of Ionian coast characterized by abandonment and depopulation phenomena. In order to make this possible, it is important to ensure a high efficiency of services allowing an easy and fast connection between the town centres, often located inland, and the coast.

6. Conclusions

The objective of this study was to verify the adequacy of a spatio-temporal model in land use changes measurement and prediction. This would be an important analytical tool available to planners and policy makers in order to address their own choices. The investigation was only partially successful: in the previous sections we have seen how the simulation carried out in the Pisticci Municipality produced a realistic trend of sprawl phenomenon. Nevertheless, in order to adopt this model in common practice, there are some gaps that need to be improved. First of all, we have to recognize that if the purpose of the study was to achieve a land use change measure, then the experience would have been substantially a failure. In fact, the term land use refers not only to the increase in built-up areas, but to all soil transformations that lead to soil sealing, and consequently to the loss of ecosystem values and of the ability to produce food or to take part in bio-geochemical cycles. The proposed investigation, however, measures the increase of built-up areas, and, therefore, only a part of soil consumption causes. The reason why it was not possible to carry out more complete measurements of consumed soil is a lack of detailed land use maps at different dates. Measure of consumed soil requires knowledge of actual land use, at least at two different times, and unfortunately, these data are not currently available for the case study. But the real intention of this paper was to verify the reliability of statistical models for spatial-temporal analysis of land use changes. In this sense, the experience was a success. Certainly, we can identify a number of aspects that should be subject of further considerations in future. The presented model, for example, determines, through a complex system of spatial variables weighing, the probability that a soil, it is better to say a pixel, changes class in land use classification. However, the basic assumption is that the balance between different variables, as well as their individual weights stays constant over time. This, especially when predictions are produced at very huge time intervals, can become a source of error. In the case of a use of the model for more extensive geographical areas, therefore, at least the realization of multiple simulations alternatives is desirable, in order to produce different scenarios according to the different weights that different variables may assume over time.

With this model, but more in general with all simulation models, a neutral prediction has been obtained that exogenous variables, as well as decisions policy, can influence. In the case of Pisticci, housing market or tourist demand changes may affect the processes of built environment development.

In fact, the decrease of housing development occurred since 2005-2006 and still prosecuting, is exclusively due to changed international and national economic conditions, and not to designed regulations limiting land use changes. In the specific case of Pisticci municipality, the inability to take into account this variable did not affect the final result, because comparing measured data of built-up areas in 2006 to those measured in 2012, an increase in built-up areas has occurred. Consequently, there was no analogy with the observed dynamics at international and national level. However, this has basically represented a chance circumstance.

Future developments in the field of land use modelling must consider the possibility to define different scenarios depending on the greater or lesser incidence of these exogenous variables.

Several socio-economic factors, such as changes in real estate values and in labour and employment dynamics, can affect land use changes. A great challenge, in order to refine capabilities of LUCC models up to date implemented, is to consider these factors in a spatio-temporal simulation. It is important to consider two aspects.

First of all it is important to take into account the difficulty in obtaining a geographic modelling of many socio-economic factors: it is fundamental that they may be included in the model. In the literature there are a lot of attempts to include these exogenous variables in the simulation. The most promising results have been obtained from WoE applications (De Almeida et al., 2002). It was possible to assess the transition probability of land use changes governing as a function of socio-economic and infrastructural factors. An approach similar to topological overlay has been adopted, evaluating their relationships with changes in different land use classes through a spatial correspondence. A second aspect is related to the variability of socio-economic factors, which often change with a speed much faster than building dynamics. Future models should include the possibility to run multiple simulations considering different scenarios based on possible socio-economic changes and, more generally, on exogenous variables.

The construction of several alternative scenarios would also consider changes in other variables in addition to socio-economic ones. The coastline, for instance, with its progressive shifting towards the hinterland can be considered as a form of indirect soil consumption. While shifting of coastline, does not directly affect building dynamics, it may produce changes in the spatial relationships between different environmental parameters, and therefore modelling of its possible change might be interesting in urban development simulations. This variable should be included assessing the distance from the coastline for each cell of the study area. Through the WoE it is possible to evaluate the impact of this distance on urban dynamics. Alternative scenarios should then produce different simulations based on the various positions assumed by the coastline.

Some general considerations on the proposed methodology can be developed. As already argued, the calibration phase is a critical point of models based on CA developed in recent decades. The model discussed in this paper, based on the use of empirical Bayesian methods, allows to significantly reduce the computational complexity traditionally associated with that phase. It is also important to consider the tendency of CA methods to exclusively determine changes in proximity of a particular cell: even large-scale phenomena are seen only through their local effects. The use of WoE, which determines the weight of each class of a given factor considering the occurrence of a given phenomenon not only at local level but considering to the entire study area, allows to overcome this limitation.

With the proposed methodology, then, the relationship between event *s* (in our case a possible new development) and a *B* factor (in the specific case one of the spatial variables) has been transformed in a relationship between event *s* and its WoE value calculated for B. The transition between the two functions occurs through class division of values assumed by the variable B.

For three main reasons, the relationship adopting WoE is more advantageous (Bernardo et al., 1985). The dependent variable *s* is linked by a monotony relationship to the independent variable B. It is therefore certain that following the increase of class of the independent variable B, the dependent variable will be always increasing or decreasing. In the case of slope, for example, the increase of this variable always produces a decrease of measured WoE, because it increases the resistance against the development of new constructions.

Secondly, it should be remarked how it is possible to calculate WoE also in the case of absence of independent variable data in a point. In the example, if we do not know values of slope above a certain threshold, we could just create a "missing values" class, for which we calculate WoE. In raster cells with unknown value of slope, variables will be in any case determined by the value of WoE variable slope.

The third advantage of WoE application is the possibility to not consider any outliers present within the sample of a given variable. These automatically fall within one of the categories defined by the user (e.g. a slope class) and therefore they assume WoE. In the following analysis, WoE will be therefore used and not the outlier, that would cause errors in calculations of average values affecting analyses results.

In order to reduce the computational complexity of the model and to analyse in more detail the impact that each variable produces compared to simulation effects, future model developments should include further statistics belonging to the family of Information Theory. The calculation of the Information Value (IV) may be particularly interesting. This statistic, directly deriving from WoE calculation, allows to calculate the overall strength of a variable (Lin, 2013). In synthesis, IV is a pure number that depends on the value used to determine whether a variable is characterized by a low, medium or strong ability to predict an event, or if it is irrelevant for modelling purposes. The IV is widely used as a variable reduction method.

IV is adopted before applying the model to reduce the number of variables to be used, selecting only those with high IV and discarding variables with low or null prediction capability of land use transformations.

With the previous specification, the described model is however configured as a useful tool to assess sustainability of planning choices, allowing to identify the best possible plan alternative for soil consumption reduction. This aspect is particularly interesting considering the growing attention on this topic, not only in scientific communities but also among policy makers. In cognitive analysis supporting planning choices it is usual to study the phenomenon of urban sprawl on the basis of evaluations of multi-temporal satellite images, while predictive models are exclusively used in research field. The development of predictive models more accurate and with a rapid application, can stimulate the use of these methodologies also in defining planning choices aimed in pursuing the objectives of soil consumption reduction.

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