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Analyzing Periurban Fringe with Rough Set

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***Abstract*—**The distinction among urban, periurban and rural areas represents a classical example of uncertainty in land classification. Satellite images, geostatistical analysis and all kinds of spatial data are very useful in urban sprawl studies, but it is important to define precise rules in combining great amounts of data to build complex knowledge about territory. Rough Set theory may be a useful method to employ in this field. It represents a different mathematical approach to uncertainty by capturing the indiscernibility. Two different phenomena can be indiscernible in some contexts and classified in the same way when combining available information about them. This approach has been applied in a case of study, comparing the results achieved with both Map Algebra technique and Spatial Rough Set. The study case area, Potenza Province, is particularly suitable for the application of this theory, because it includes 100 municipalities with different number of inhabitants and morphologic features.

***Keywords*—**Land Classification, Map Algebra, Periurban Fringe, Rough Set, Urban Planning, Urban Sprawl.

I. INTRODUCTION

In a few years' time a transition has been occurred from the traditional town, characterized by static social contexts, to today's city more dynamic and very hard to control in small details. Until few decades ago the social structure of the city was characterized by a population with strong social ties, whose life was oriented by institutions, rules, authorities. These inhabitants are now leaving the historic part of the cities more and more occupied by transition population (students, tourists, etc.). Often the centre of town is a big shopping centre with museums, libraries and other services but without residents. The new population neither has roots in those places nor the prospect of living there for the whole life. Older inhabitants have moved out of the urban area by creating a sort of dispersed spatial form [8]. This phenomenon occurs on the fringe of urban areas through progressive "coagulation" of buildings. Neighbourhoods without centre and with poor social relation-ships have been realized. This form of urban sprawl has been encouraged by the increase of number of infrastructures, the growth of income and demand for goods and services. Urban sprawl can be considered a long-term trend for successful economic-territorial systems [3], characterized by soil consumption generating loss of competitiveness for agricultural activities [12], [22], [24], [25], [26] [27]. The term periurban area has been recently coined in order to represent this sort of transition city and it has been frequently used in planning documents. One might ask: “what does periurban area mean, exactly?”. This term is not fully understood from planners, because planning systems do not give a clear and unambiguous definition. Urban planners have two different approaches: the first one considers the phenomenon from a theoretical point of view, in comparison with the consolidated concepts of city and rural area; the other one takes into account the increase of real estate economic value, due to the transformation. A clear definition of periurban fringe can be achieved considering this zone as an area with its own intrinsic organic rules, such as the urban and rural ones and not as a transition zone from urban to rural areas. For instance, proximity to urban areas, contiguity to road network, presence of utilities and urban services, population density higher than in rural areas can generate a set of inclusion rules and if some of these rules are satisfied, the area can be included in the periurban fringe. In the same way, exclusion rules consider archaeological sites, heritage areas, environmental preservation areas, steep slope terrains, landslide areas, erosion areas. If even one of these rules is satisfied, the area cannot be included in the periurban fringe. The possibility of providing different degrees of land suitability has become more and more feasible in site selection by the use of geographical information systems combined with evaluative methods. In the literature about land classification, a relevant number of experiences combining GIS with multicriteria methods or fuzzy set approach exists [4], [9], [10], [14], [18],[21], [23], [28]. Only few experiences exist in land suitability analysis using Rough Set. This approach has been tested in the case of study of Potenza Province. The phenomenon of urban sprawl is very common, despite the small number of inhabitants in the studied region.

II. MAIN ELEMENTS OF ROUGH SET THEORY

Rough set theory [6], [15], [16], [17], is based on the hypothesis that each element is associated to several information in the Universe of discourse. Some objects are indiscernible from others if they are classified in the same way according to their associated information. In other words, two different elements can be indiscernible in some circumstances while in other contexts they may belong to different classes. This methodology is based on the concepts of indiscernibility relation, upper and lower approximation and accuracy of the approximation.

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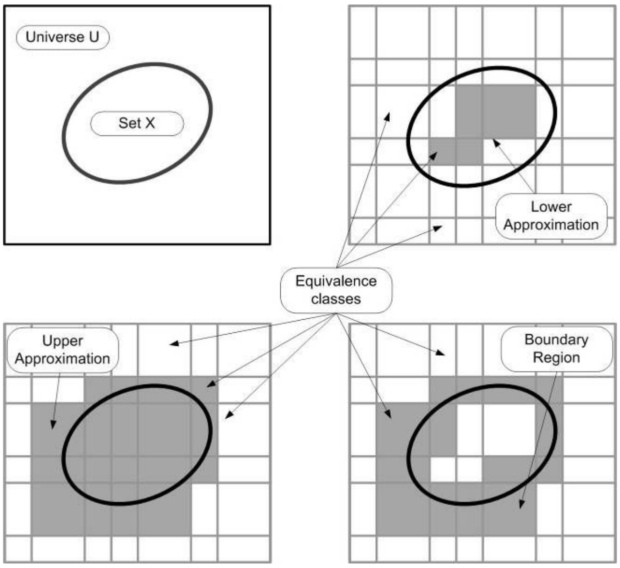

Fig. 1 Boundary, Upper and Lower Approximation of a set X.

In an *Information System* IS=(U,A), U is a set of defined objects U= X_1, X_2,…., X_n and A is a set of attributes A= a_1, a_2,…,a_n. U and A are non empty sets. For each attribute $a \in A$, we associate a set of values V_a called domain of *a*. It is possible to define an attribute in order to classify all cases. A *Decision System DS=(U,A*$\cup$*d)* is an information system in which a decision attribute, *d*, affects the classification.

If we consider a set of attributes B$\subset$A, it is possible to define the following indiscernibility relation Ind(B): two elements (Xi, Xj)$\in$ Ind (B) are indiscernible by the set of attributes B in A, if b(Xi)=b(Xj) for each b$\subset$B. The equivalence class of Ind (B) is called elementary set in B. Lower and upper approximation (Fig. 1) are defined as the elements contained with certainty in the set and as the objects which probably belong to the set, respectively. The difference between upper and lower approximation defines the boundary of set X . If boundary is equal to 0 then the set X is Crisp. The accuracy is defined as the ratio of cardinality of lower and upper approximation. The result must be included between 0 and 1.

III. THE CASE STUDY

Potenza Province is located in Southern Italy; it has a low population density (400,000 inhabitants, over 650,000 hectares). The main town is Potenza with 70,000 inhabitants, while the other municipalities can be classified in three groups. Twelve towns count more or less 12,000 inhabitants, twenty municipalities have a population of about 5,000 inhabitants, the population of the remaining 67 municipalities varies from 700 to 2,000 inhabitants. Generally urban sprawl is more common in metropolitan areas, whereas it is not frequent in regions with low population density. This phenomenon in small municipalities is generated by the abandonment of old town centres, while in bigger towns it is produced by high costs of flats. An accurate analysis of the phenomenon has been carried out using all the potentialities of Geographical Information Systems. All the polygons which represent buildings have been converted into points in order to use spatial statistic techniques. The number of flats for each building indicates the intensity of the event in order to achieve a continuous surface of spatial densities [1], [2], [11]. In the application a bandwidth value of 400 m has been used with a grid cell dimension of 10 m. The phenomenon intensification has been evaluated calculating kernel density from cartographies at 2004 and 1987. This comparison has highlighted more precisely zones with the greatest growth of urban sprawl phenomenon. After the localization of areas where the phenomenon is more considerable, it is important to understand the factors which could lead to its increase.

Kernel density can give further interpretations of the settlement dispersion phenomenon. Growth has been developed as a crown surrounding the urban area or along the road network and it is indiscriminately located on landslides and steep slopes. The greatest increase of urban sprawl has occurred in zones mostly situated on mountains, while urban growth is considered as a threat in areas with intensive agricultural activities. In the study case, kernel density has been considered according to the following classes:

- it is reasonable to classify a region as rural if the presence of flats is less than 1/ha;
- from 1 to 5 flats/ha, it is possible to define the periurban class;
- urban features are predominant beyond 5 flats/ha.

The second class generated by Kernel density is exactly one of the inclusion rules adopted in the application. The phenomenon of urban growth has been observed in various municipalities with different sizes and this study indicates that new buildings are completely within a distance of 200 m from the road network. Proximity to road network has been calculated by means of straight line distance, assigning a distance value to each cell. Areas where distance between buildings is less or equal to 100 m. have been obtained by means of nearest neighbour distance. Distances from road and between buildings complete the set of inclusion rules. The following exclusion rules have been considered: area included within a distance of 150 m from rivers and streams, slope higher than 35%, Nature 2000 sites, zones at hydro-geological risk. These inclusion and exclusion rules have been combined with contiguity rules. Depth of contiguity zone, for each centre, has been located using a shape index for the boundary of the urban area. Shape index is the ratio between the perimeter of the urban area and the perimeter of the circle that inscribes it. It is obvious that such index can assume values greater than one. The more the value is greater than one, the more the shape of the settlement will be long, jagged and narrow. A good level of compactness corresponds to a shape index comprised between 1 and 1.6, a medium level to values between 1.61 and 2.4, a low level to an index greater than 2.4. In Table I the 100 municipalities of Potenza Province are grouped in three classes according to compactness rate. This table highlights the low level of compactness of urban areas of Potenza Province.

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TABLE I
CENTRE CLASSES BASED ON COMPACTNESS RATE

	Index value	Number of Centres
Good compactness	1-1,6	12
Medium compactness	1,61-2,4	68
Poor compactness	2,41-4,81	20

Two criteria have been considered for contiguity: the first one is the ratio between area and perimeter of the urban region; the second is the ratio between area and perimeter of the circle inscribing the urban region. All these rules with the same thresholds have been adopted in both techniques Map Algebra and Spatial Rough set.

A. Land Classification with Map Algebra

Three different periurban areas have been identified by combining the previous rules with map algebra (Fig. 2):

- the first edge has been obtained considering all previous (inclusion-exclusion) rules and first contiguity, which takes into account the ratio between area and perimeter of the urban region;
- the second boundary has been achieved considering all previous rules and the second contiguity, which considers area and perimeter of the circle inscribing the urban region;
- the third zone does not take into account any contiguity.

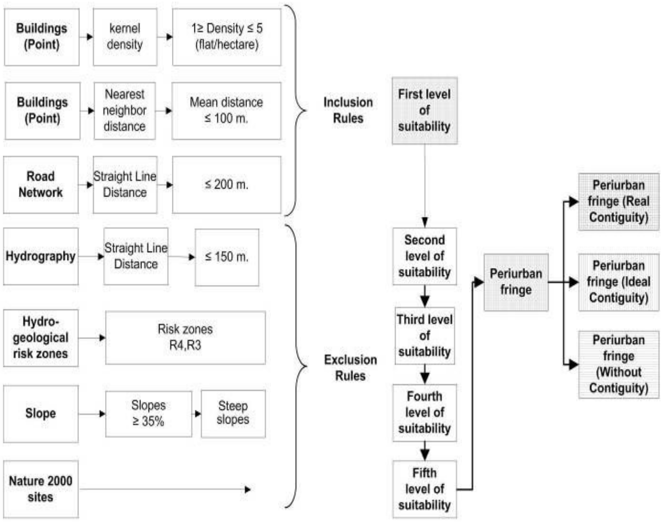

Fig. 2 Scheme of the procedure for the location of Periurban fringe

As expected, results are rather different according to type of periurban area. In most municipalities, the smallest area is achieved considering the first of cases mentioned above. The biggest region is yield without considering any contiguity rule.

This trend is completely reversed in the case of Potenza municipality (Fig. 3). The periurban fringe obtained without taking into account any contiguity rule is the smallest one, because the kernel function captures a low density of buildings in these zones. This result implies that areas close to the urban region are represented by settlements with at most 2 flats for buildings. In confirmation of this hypothesis the relationship between the two periurban fringes and the two contiguity rules hold the same sequence.

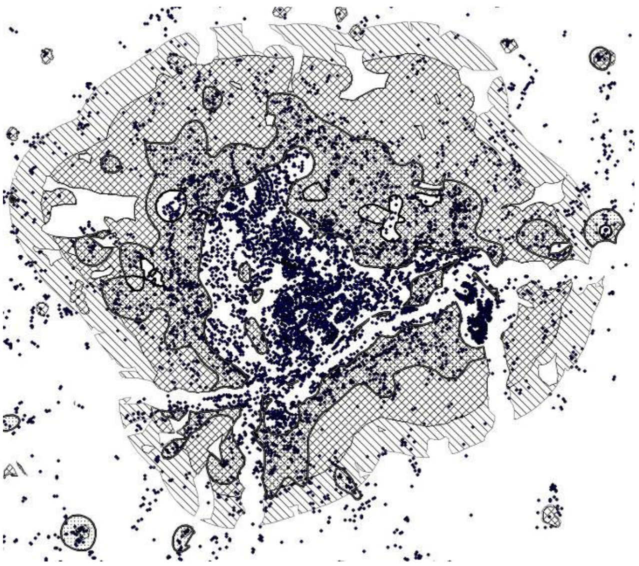

Fig. 3 Comparison among the three periurban fringes in Potenza municipality. The inner area (dotted hatch with bold boundary) does not consider the contiguity. The intermediate zone (squared hatch) adopts the first contiguity rule, the outer region (hatch with lines) uses the second contiguity rule

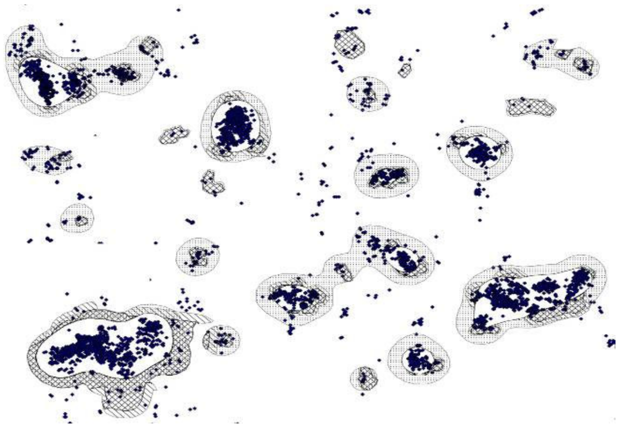

Fig. 4 Avigliano, middle size municipality, the squared hatch adopts the first contiguity, the hatch with lines uses the second contiguity rule and the dotted hatch does not consider the contiguity

However, the greatest part of cases follows the order "first contiguity rule - second contiguity rule -without any contiguity rule". Considering the morphology of settlement system of Potenza Province, constituted in most of cases by urban areas sited on the spire of Apennine and scattered settlements located near the road network along the valleys, the contiguity rule does not entirely capture the phenomenon leading to a wrong interpretation. Considering Avigliano municipality (Fig. 4), the use of contiguity rules implies the exclusion of north-western and south-eastern settlements. From Fig. 4 it is easy to understand that the transition from the first to the second contiguity rule does not cause a large increase of extension. In this figure a huge increase of periurban fringe is yield without any contiguity rule, which better represents the actual situation. In all cases, the more reliable region is the third one which is achieved without any contiguity rule, because it identifies the areas in which new transformations are more likely to occur.

B. Land Classification with Rough Set Theory

Rough Set theory has been applied for the classification of different geographic layers. In the case of study, the whole provincial territory represents the universe [U]; inclusion and exclusion rules are the attributes [A] (Table II) and objects (cells of the grid) have been classified following previously defined rules. Indiscernibility relations have been calculated in [U] considering attributes, obtaining the subset [X].

TABLE II
ATTRIBUTES AND DECISION VARIABLES FOR ROUGH CLASSIFICATION

Attributes and decision variable	Values	Inclusion rules
B= Nature 2000 sites	0 Nature 2000 sites 1 different from Nature 2000 sites	1 different from Nature 2000 sites
Fi= Hydrography	1 if the distance is less than 150 m. 2 if the distance is included between 150 m. and 800 m. 3 if the distance is bigger than 800 m.	2 if the distance is included between 150 m. and 800 m. 3 if the distance is bigger than 800 m.
Fr = Hydro-geological risk zones	0 classes R3 ed R4 1 different from classes R3 end R4	1 different from classes R3 end R4
P= Slope	1 if the slope is less than 23,6% 2 if the slope is included between 23,6% and 35% 3 if the slope is bigger than 35%	1 if the slope is less than 23,6% 2 if the slope is included between 23,6% and 35%
D= Density	1 if the density is less than 1 flats per hectare 2 if the density is included between 1 and 5 flats per hectare 3 if the density is bigger than 5 flats per hectare	2 if the density is included between 1 and 5 flats per hectare
V= Road Network	1 if the distance is less than 200 m. 2 if the distance is included between 200 and 700m. 3 if the distance is less than 700 m.	1 if the distance is less than 200 m.
C1= Real Contiguity	0, 1	1
C2= Ideal Contiguity	0, 1	1
Nei= Nearest neighbour distance (Decision Variable)	1 if the minimum distance is less than 100m 2 if the minimum distance is included between 100 and 200m 3 if the minimum distance is bigger than 200m	1 if the minimum distance is less than 100m 2 if the minimum distance is included between 100 and 200m

Therefore, all the cells which satisfy at the same time exclusion and inclusion rules are assumed as a subset [X], contained in [U]. The decision system in this case is composed by the set X, i.e. the set of attributes where the decision variable is the nearest neighbour distance.

Set X has been obtained according to the decision variables (NEI) in order to achieve its lower and upper approximation. Three classifications have been done. Two ones take into account the first and the second contiguity rules, respectively; the third one does not consider any contiguity rule. Lower and Upper approximation, and accuracy for NEI equal to 1 have been computed for each case. In the case of Real Contiguity, Lower approximation belongs to the set X and at the same time it is included in first contiguity belt with NEI equal to 1. Upper approximation follows the same rules of the Lower approximation with the exception of NEI which can be equal to 1 or to 2 (Table III).

TABLE III
DECISION TABLE, LOWER AND UPPER APPROXIMATION AND ACCURACY WITH REAL CONTIGUITY

B	Fi	Fr	D	P	V	C1
1	2	1	2	1	1	1
1	3	1	2	1	1	1
1	2	1	2	2	1	1
1	3	1	2	2	1	1

Nei 1	Nei 2	Total	Lower	Upper	Accuracy
103914		103914	138056	435856	31,67%
297750	50	297800			
8946		8946			
25196		25196			

TABLE IV
DECISION TABLE, LOWER AND UPPER APPROXIMATION AND ACCURACY WITH IDEAL CONTIGUITY

B	Fi	Fr	D	P	V	C2
1	2	1	2	1	1	1
1	3	1	2	1	1	1
1	2	1	2	2	1	1
1	3	1	2	2	1	1

Nei 1	Nei 2	Total	Lower	Upper	Accuracy
121089	32	121121	44214	523862	8,44%
358388	139	358527			
12127		12127			
32087		32087			

TABLE V
DECISION TABLE, LOWER AND UPPER APPROXIMATION AND ACCURACY WITHOUT CONTIGUITY

B	Fi	Fr	D	P	V
1	2	1	2	1	1
1	3	1	2	1	1
1	2	1	2	2	1
1	3	1	2	2	1

Nei 1	Nei 2	Total	Lower	Upper	Accuracy
231461	102	231563	72857	928856	7,84%
624127	309	624436			
20390		20390			
52467		52467			

Comparing results of the three cases, Real Contiguity rule produces the best results (Tables III, IV, V) with a better interpretation of the phenomenon (Fig. 5, 6, 7, 8, 9, 10).

IV. RESULTS AND FINAL DISCUSSION

Comparison among the results achieved using Map Algebra technique and Rough Set method is the most interesting issue (Fig. 5, 6, 7, 8, 9, 10).

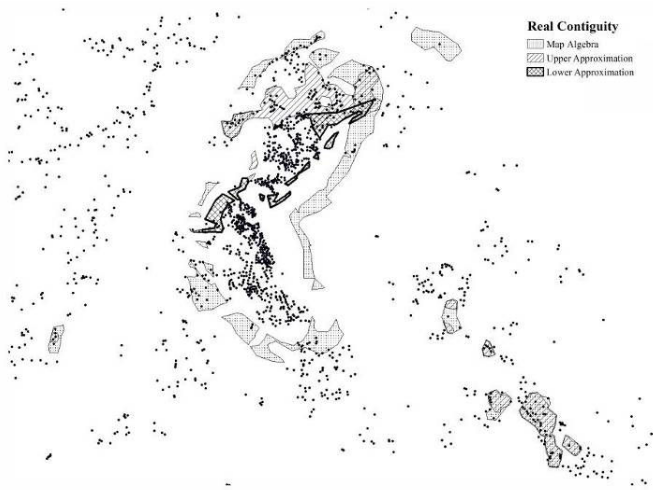

Fig. 5 Comparison among the periurban fringe obtained with Map Algebra and Rough Set considering real contiguity for Lauria municipality

Fig. 6 Comparison among the periurban fringe obtained with Map Algebra and Rough Set considering ideal contiguity for Lauria municipality

The periurban fringe achieved by means of spatial rough set is the smallest one in all municipalities and with every kind of contiguity. This tendency may be due to several factors: how certain combinations of attributes are interrelated; map algebra adopts Boolean operators, based on the true-false logic, producing either too narrow or too wide areas; decision variable influences results in a certain way, for this reason it is more important to adopt a decision variable which is a sort of key factor for the phenomenon to represent.

The results showed in Fig. 5 to Fig. 10 are confirmed in Table VI, which summarizes results achieved with each classification method, taking into account cell number included in periurban fringe.

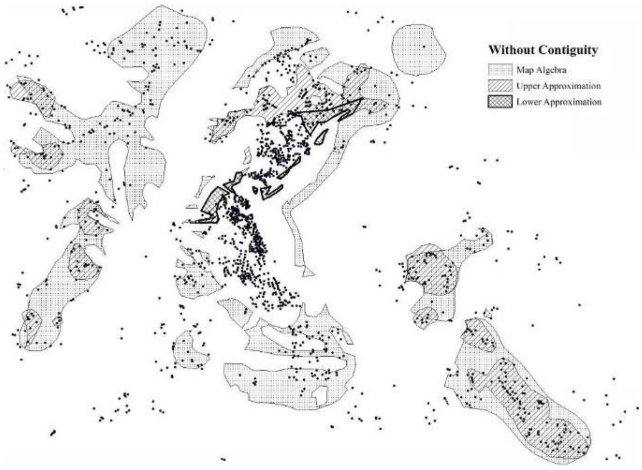

Fig. 7 Comparison among the periurban fringe obtained with Map Algebra and Rough Set without considering any contiguity rule for Lauria municipality

TABLE VI
DECISION TABLE, LOWER AND UPPER APPROXIMATION AND ACCURACY WITHOUT CONTIGUITY

	Map Algebra	Rough set		
		Lower	*Upper*	*Accuracy*
Without Contiguity	1721768	72857	928856	7,84%
Real Contiguity	766864	138056	435856	31,67%
Ideal Contiguity	1208171	44214	523862	8,44%

Fig. 8 Comparison among the periurban fringe obtained with Map Algebra and Rough Set considering real contiguity for Picerno municipality

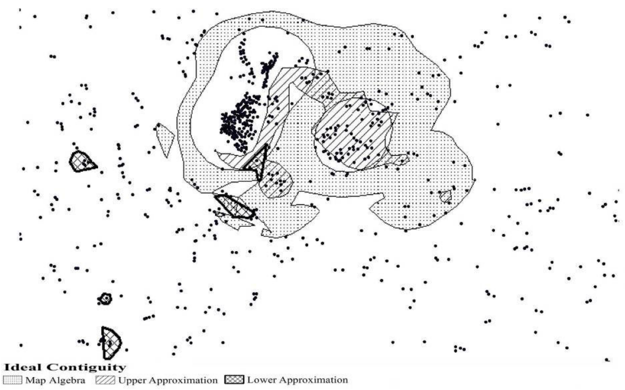

Fig. 9 Comparison among the periurban fringe obtained with Map Algebra and Rough Set considering ideal contiguity for Picerno municipality

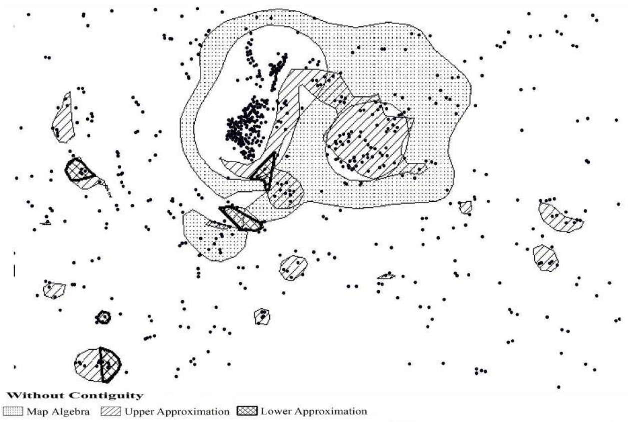

Fig. 10 Comparison among the periurban fringe obtained with Map Algebra and Rough Set without considering any contiguity rule for Picerno municipality

Despite widely held that Rough Set evaluations are used to achieve more soft constraints, our results show that the classification with Map Algebra produces a periurban fringe with a larger extension, while rough classifications generate a narrower fringe. Among the rough classifications, real contiguity produces an acceptable accuracy and it is more close to reality.

V. CONCLUSION

The spatial simulation using Rough Set theory is particularly suitable in defining the periurban belt and represents an important improvement in decision-making process predicting future scenarios. The periurban phenomenon is a case with a high level of uncertainty, with ill defined data for the whole area and not much clear rules. Sorites paradox perfectly describes the periurban phenomenon: two or three buildings do not make a town; a million buildings do make a big town; if n buildings do not make a town neither do (n+1) buildings; if n buildings make a town, so do (n-1) buildings. The first property combined with the third one implies that a million buildings do not make a town, in contradiction with the second property. In the same way, a combination of the second and fourth properties shows that two or three buildings do make a town, in contradiction with the first property [5]. Urbanization growth represents one of the main environmental threats of last decades. Several approaches have been adopted in analyzing this phenomenon, mainly related to different study domains. Urban sprawl, soil consumption, settlement risk, and even the attempt to reach a distinction between urban, peri-urban, exurban, rur-urban and rural areas are different sides of the same coin which examine the huge amount of negative aspects generated by urban expansion summarized in soil sealing, loss of productive agricultural lands and forest's cover, habitat destruction and fragmentation, waste of energy, pollution, landscape degradation. Consequently, urban growth generates environmental impacts at local, regional and global scales. Considering sustainability with a systemic approach, the periurban fringe represents the typical case where economic, social and environmental systems have always to be considered. The concept of sustainable development is a synthesis and a balance of three factors: social justice, economic utility and environmental integrity [7]. For this reason it is important to pay attention to periurban areas, if it were permitted uncontrolled sprawl there would be an unsustainability under three points of view [13]:

1. environmental: urban sprawl is one of the hugest environmental threats;
2. social: urban sprawl obliges people to travel many hours per day, leading to a total absence of social and neighbourhood relationships;
3. economical: urban sprawl produces agglomeration disadvantage in localizing services and activities and in realizing interventions and infrastructures [19], [20].

The areas achieved in the case study in an indiscernible way the region where the new development areas can be located.

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