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*Full Length Research Paper*

# Spatial analysis of the increasing urbanization trend in the Frascati wine designation of origin (DOC) area: A geostatistical approach

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**This work refers to the design, test and implementation of an estimation index useful to describe cultivated areas reduction in a sub-urban context. The index is based on the historical analysis of the interference between urban development and agricultural activities, and it uses geostatistical methods. The necessary data to implement the index has been derived from heterogeneous sources covering a period of about 10 years (1996 to 2005). Joint use of optical satellite images at high/very high spatial resolution and numerical cartographic data has been essential. More in detail, the index has been tested in the estimation of land use changes for the period of 2005 to 2008 in the study area. Results have been verified through a very-high-resolution (VHR) Kompsat 2 satellite image acquired in 2008.**

**Key words:** Geographical information systems (GIS), urban sprawl, area profile index, prediction models.

## INTRODUCTION

“Sprawl” expresses the development pattern and pace, in which the land consumption rate for urban needs exceeds the population growth rate, resulting in an inefficient use of territory and resources. Urban sprawling expansion constitutes a kind of colonization of the countryside that is not naturally induced by necessity, but an exponent of speculative development, private land hoarding and often the private appropriation of values created by public investments (Espon, 2006).

However, nowadays, the extensive growth of urban areas that affect agricultural lands is considered a normal phenomenon. The impact of urban sprawl on rural areas is clear in many European megacities, such as London or Moscow, as a consequence of the population movement towards suburban areas. The same problem occurs also in smaller urban areas: for example, in Glasgow and Liverpool (UK) , the combined urban population was reduced by 38% in 1970; in the same year there was an urban population shift of 12% in Marseille and of 9% in Paris (France), of 26% in Milan and 15% in Naples (Italy), while the metropolitan areas of those cities increased. On the contrary, in Milan area (Lombardy Region, Italy) the urban sprawl had a minor and slower impact (Savitch, 2000). In all these cases, the phenomenon of urban sprawl has been often accompanied by urban fragmentation and the spread of a mesh of large sized buildings in the area.

Scientists (Batty, 1976; Batty and Jiang, 1999; Herold et al., 2003; Biondi et al., 2003; Romano, 2004, Ioannilli and Ambrosanio, 2006) have applied many indicators and numerical models in the fields of nature protection, land cover and land use changes, in soil, marine and coastal areas, and in the urban areas. In particular, urban patterns determined by formal and informal policies allow us to identify the driving forces of urban sprawling, so that we can understand and improve urban planning processes.

In these methodologies, the approach of cost benefit analysis of the phenomenon in environmental contexts can be measured by different techniques. Accordingly, the sprawl size is analyzed using specific indicators suitable for measurements of different physical, chemical, ecological and social aspects. The problem, then, is

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**Abbreviations: AGEA,** vineyards register; **API,** area profile index; **IGMI,** Istituto Geografico Militare Italiano; **ISTAT,** National Statistic Institute; **DOC,** designation of origin; **PRG,** urban general plan; **VHR,** very high resolution.

choosing the optimal indicator to measure individual factors and to make comparisons with alternative methodologies. Indicators are only a “sign” of a possible environmentally related effect, and not exactly the measure of the effect itself. Therefore, the choice of appropriate techniques is essential in determing the possible effect caused by the driving forces, otherwise there is always a risk of showing a different or wrong effect than the real one produced in the process of sprawling (Bresso et al., 1990), moreover, it is worth noting that all current indices tend to describe the spatial and functional organization of natural systems components. Often, an index involves more than one aspect of this organization, this results in a loss of relationship between the measure and the specific system component. Moreover, being typically dynamic, the adopted index must be determined explicitly in terms of hypotheses of the processes taking place in the systems themselves; otherwise, it would not be easy to define a genuine correspondence between the resulting value of the index and the corresponding meaningful information. Therefore, in order to better define a correspondence between index values and the spatial configuration of a typical dynamic system, such as that of the suburb of Rome, it was necessary to develop a new methodology for the specific phenomenon of urban sprawl.

The first objective was the evaluation of anthropic pressure in Frascati DOC vine area (and its municipalities) with respect to the urban sprawl effects. In order to assess the urban sprawl impact on agricultural areas, and the so called area profile index (API) has been developed. This index is based on the comparison (topological) among the different land uses in GIS environment.

## The area profile index

The API index allows the measurement of the spatial profile of each land use class in a fixed area. The spatial profile is evaluated in terms of spatial pattern of each land use and spatial relationships among different land uses. By using the API index, a forecasting model was developed, in order to identify, in a reference period, areas with higher risk of change. A validation analysis was carried out to asses the accuracy of the model. The API is based on a geostatistical approach: the aim is to obtain some basic measures of the spatial distribution usage, both for a single municipality and for the overall DOC area.

The area profile index formula is:

$$API_{xi} = \frac{S_x \cdot (C_i / C_t)}{S_t} \quad (1)$$

and the overall density value for a specific land use x:

$$API_i = \sum_x \frac{S_x \cdot (C_i / C_t)}{S_t} \quad (2)$$

where $API_{xi}$ is the area profile index for the density class i and the land use x, $S_x$ is the total area for the specific land use (x), $C_i$ is the number of cells in density class i, $C_t$ is the total area cells and $S_t$ is the total municipal area.

The API was defined in order to produce a quantitative descriptive summary of the spatial arrangement of the different land uses, which allows to easily understand the environmental framework of the territory. A logical model was adopted to evaluate the API. It is based on the measurement of spatial relationships among the density distribution of each land use and on the comparison of each distribution with the total amount of each specific land use area. To simplify the system, the study area was divided in two land use classes: agricultural and urban. These two variables are inversely related: increasing the first and the other decreases.

The API was applied to analyse the specificity of a single municipality and to compare each municipality profile with the entire production area of the Frascati DOC. Concerning the study area, the increasing urbanization has resulted in a reduction of a farmland within its borders. Moreover, there is more dispersive urban sprawling than massive and compact urbanization. The adopted index characterizes each municipality with a synthetic value, notwithstanding the total size of the study area. Moreover, this index takes into account how urban areas and crops are distributed.

## Study area

The city of Rome (Italy) is characterized by a large Municipal Territory, for which population shift towards surrounding municipalities has produced and continues to produce an impressive increase in buildings. The area of the Frascati DOC, vineyards is situated at about 20 km from the urban centre of Rome in the North West side of the big Latium Volcano enclave.

This study covers an area of about 8,290 ha and it has been undertaken to highlight the impact of the growth of urban areas (urban sprawl) within rural areas and also, to identify the productive potential of the remaining countryside.

Figure 1 shows a Landsat TM Image of an area around the Frascati DOC area that is composed of a complex morphology, with clearly distinguishable altimetric zones. The Frascati DOC wine production boundary includes Frascati, Monteporzio Catone, part of Rome and Montecompatri, covering a total area of 8297 ha (Fusco et al., 2004). This type of agriculture is getting critical due to the progressive loss of rural territory. The ISTAT/EU

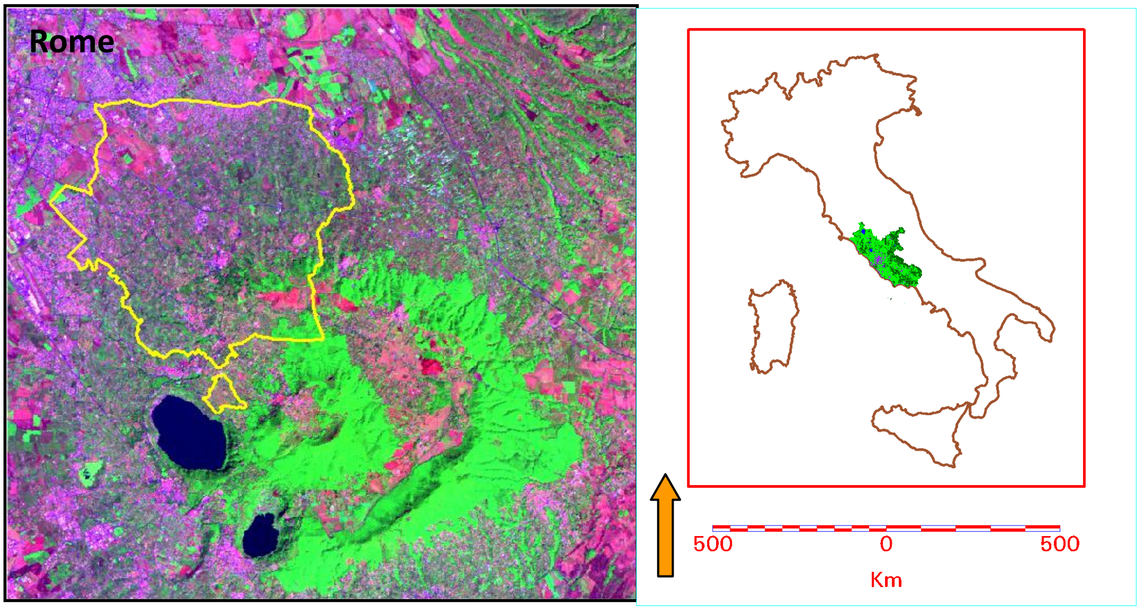


**Figure 1.** Landsat TM image (7,4,1 rgb) of the Alban Hills volcano (Latium, Italy) and, in yellow, the DOC area.

data (Istat, 1992; Eurostat, 2008) and local inspections (vineyards records and production declarations) confirm a rural territory surface decrease in the last twenty years, especially in the municipality of Rome where urban sprawl caused a loss of 63.4% (data reported from 1982 to 2005) of its original cultivated area (Tempesta et al., 2007). However, for companies that produce high quality wines, there is a significant improvement and this, in part, raises the local economy.

## Data

This work has been developed by means of the technical resources provided by ESA-ESRIN EOP Laboratories, located near Frascati (Italy), in collaboration with DISP "GEOINFORMATION" of Tor Vergata University of Rome. The geographic information system (GIS) uses dedicated software for image processing and GIS ("Erdas Image 9.1", "Envi 4.4", "MapInfo 7", "ArcInfo 9.3"), available in a network system.

Satellite images and maps were geo-referenced into the UTM projection "European Datum 1950 F33N". Two information classes are available in the informative system (GIS): the first class of information is represented by maps whose data were the basis of characteristic classes of the GIS. These classes include highway network, administrative boundaries (municipality, province), Frascati DOC area and cartography of urban planning.

All other data were obtained from manual digitization of high resolution satellite images: they include the urbanized areas (buildings) and rural areas (vineyards and olive trees). Satellite data acquired in the period of 1996 to 2004 have been strengthened with the Italian Agency for the financing of agricolture (AGEA) data and then, updated with images acquired in August 2005.

## METHODOLOGY

The urban and agricultural data analysis for Grottaferrata, Frascati, Monteporzio, Roma municipality and the whole DOC area was carried out with the following procedure:

The urbanized and rural areas were modelled with digitized polygons derived from QuickBird images (for the years 2002, 2004 and 2005). Initially, the derived information layer was used to detect only the cultivation of vineyards (BACCHUS EU Project), and then, a new classes was created which also included the cultivation of olive groves. Finally, for the necessary control, the complete dataset was updated for the year 2008 by means of a VHR Kompsat 2 satellite image (Loret, 2010).

The basic recorded attributes are "type" and "area" essential to define the type of crop and to measure its cultivated surface. The same type of updating has been used for urban areas (layer of buildings), in order to analyze the density in that area.

Polygons of the layer representing the agricultural crops and buildings were transformed from vector to raster formats. The system was partitioned into physical zones, or cells, which are small enough to illustrate individual and historical characteristics, such as distinct land uses.

The data of the entire area of the map were subdivided into a grid of tiny cells, where the value is stored in each of these cells to represent the nature of whatever is present at the corresponding location on the ground. In this work a grid of 10 × 10 m was used to convert the polygons of the buildings and a 50 × 50 m grid to convert the polygons concerning crops.

From these cells, with the "conversion raster to point" the centroid of the polygon was extracted. Then, having applied the Kernel density function (Scott, 1992; Silverman, 1986) to these "centroids", a "Grid file" was obtained for estimating the statistical values of the

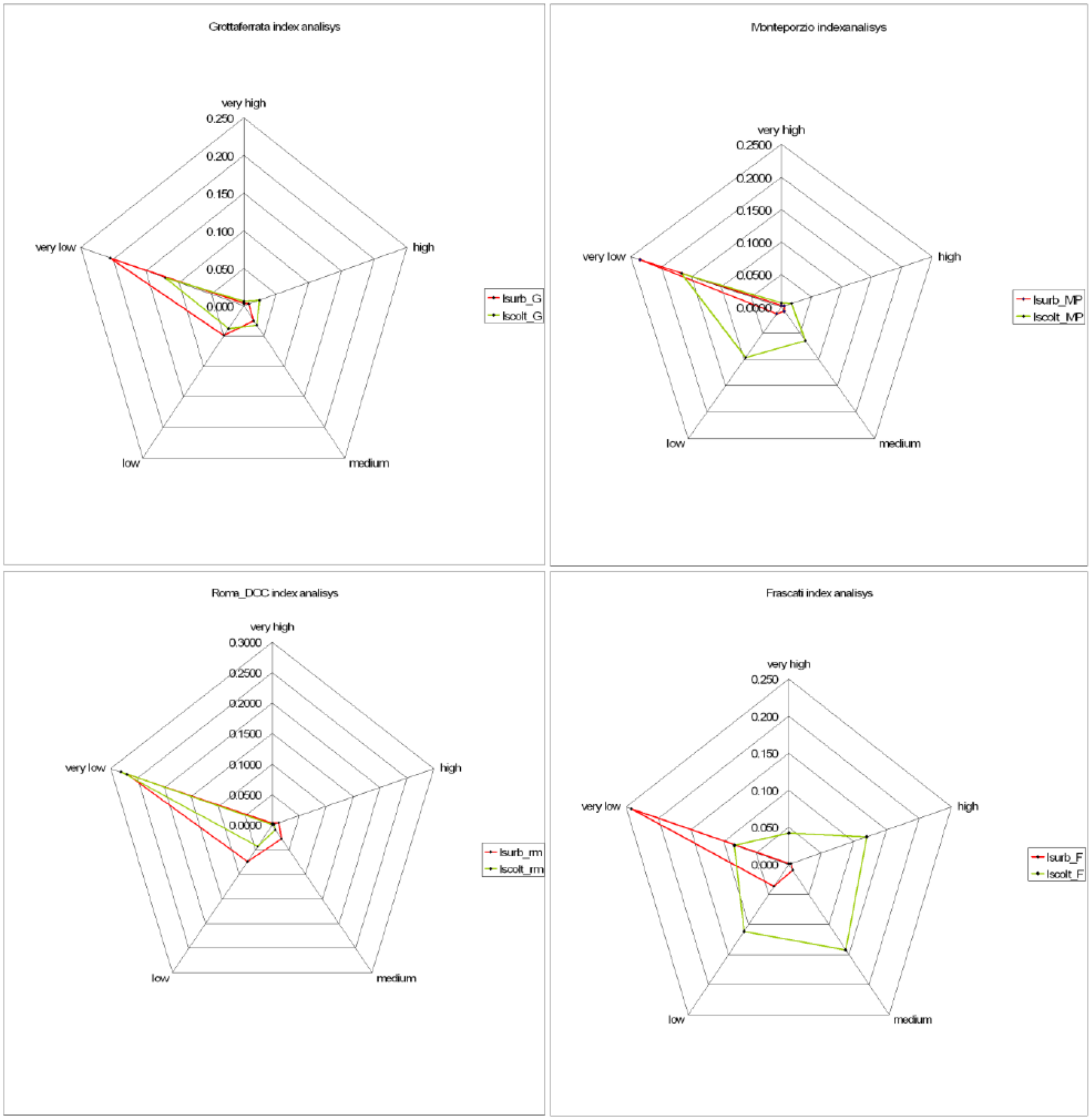


**Figure 2.** The graphs for the land use characterization (AP index values) of Frascati (lower right) and other municipalities. In red the urban areas, in green the vine crops.

density function.

The raster file (GRID) has been reclassified into 5 classes (values of grid code), corresponding to a recognized field "value", and the output value ranging from "low" to a "very high" value. Subsequently, the raster file was converted into vector format, maintaining the value of these 5 classes in the table attributes. The next step was to create a vector grid cell of 50 × 50 $m^2$ meters, which corresponds to an old establishment measure of length called "fourth or half Frascatana Pezza" (Martini, 1883), and was added to the file previously produced, that was then cut, based on the boundaries (limits) of the selected towns.

After having reworked the selected fields and counted the cells extracted for each value, the API index (4) was calculated both for rural and urban areas to make a characterization of the territory under study. Here, the application of this index to the whole DOC area and to the 5 municipalities is discussed.

This is even more evident by comparing the "very low" peak in the 4 graphs of the municipalities. This indicates that in each of them the dispersion of the buildings is very high. So, taking into account the proximity to the urban area and the great development of the road network, it can be stated that this is a good clue to analyze the phenomenon of the urban sprawl.

However, in some cases, the agricultural component (green polygon) in the study area still shows resistance to urban conversion and the comparative analysis of the four towns shows for the first two, that the crop areas around Grottaferrata and Rome (DOC) have already been overcome by the urbanization, while for the Frascati and Monte Porzio municipalities the traditional agricultural practices (olive groves, vines) are still very present (Figure 2).

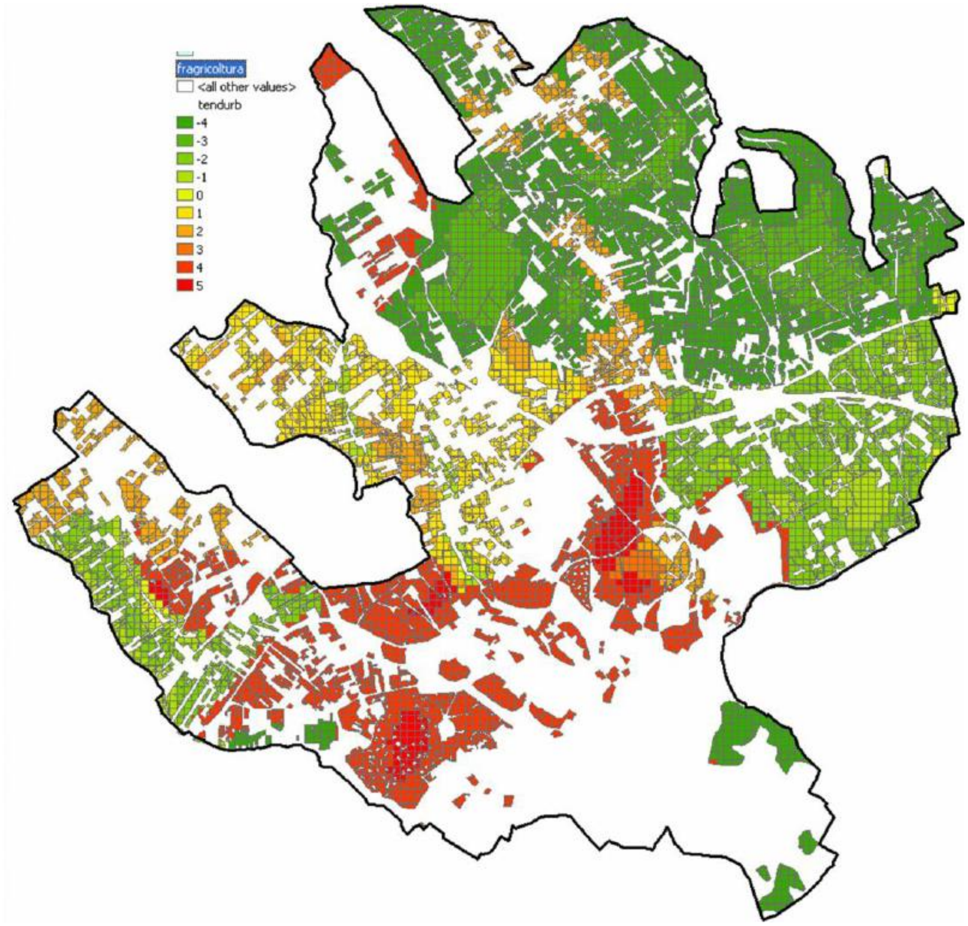


**Figure 3.** Municipality of Frascati, the agricultural land in 2005 (vineyards and olive groves) and its risk of urbanization (color coded, red highest and green lowest risk).

**Forecast of land use change probability**

After applying the urban and agricultural index calculation, we have the possibility to put these values in the following algorithms to make a prediction of the future areas of study; the predictive model was applied only for Frascati municipality. The forecast shows strong land use changes in the area and the probability of occurrence within years ahead, this allowed a temporal projection for the crops at risk of disappearance (due to land transformation in urban areas). For this specific municipality (22,58 $Km^2$ ), an accurate analysis was made from data as PRG and PTPG , provided by local documentation (that is, “General municipality town plan” and from the “Provincial general plan”), in the attempt of estimating the transformation trend of the territory. Note the input of rural area (colture05frascati.shp) and urban area (Edifici frascati2005.shp).

The construction of the predictive model is based on the assumption that the variation of the surface depends on two antithetical terms (weights). The first, “Urbanval”, responsible for the growth of the land value in urban areas while the second term, “Agrival”, which opposite to the first, is taken as the value of agri-environmental and alternative to urbanisation.

In the synthesis process file, two new fields “trendcult” and “trendurb were added, as well as weighting functions “Urbanval” and “Agrival”, which were derived from the analysis of the municipal plan.

Due to urbanization increase and subsequent loss in rural land caused by the fragmentation of cultivations, the analysis was focused on urban trend “Trendurb”, as well as on “Trendcult” data, defined by the following algorithms:

“**Trend_urb**” = int (( Kvali *Apiurb) + ( urbanval – agrival)) (3)

“**Trend_cult**” = int (( Kvali *Apicolt) + (agrival – urbanval)) (4)

Where: $Kval_i$ = Kernel density value,
Urbanval, Agrival = weights from the urban or agricultural value
Apiurb, Apicult = API indexes

## VALIDATION OF RESULTS

The goal is to use the fields of the attribute matrix of the “fragricoltura” layer to calculate a future trend. Another

**Table 1.** Loss of rural area in the municipality of Frascati from 2005 to 2008.

| Year | Vineyards (ha) | Olive groves (ha) | Total cultivation (ha) |
|---|---|---|---|
| 2005 | 659.29 | 423.19 | 1082.48 |
| 2008 | 650.57 | 371.42 | 1021.99 |
| Difference (2005 - 2008) | 8.72 | 51.77 | 60.49 |

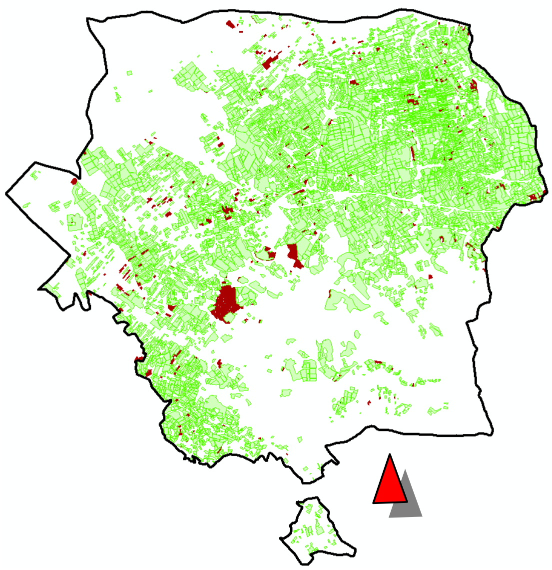

**Figure 4.** Vineyards and the olive-groves (in red) missing in 2008.

**Table 2.** Frascati DOC area loss of cultivation surface in hectares from 2005 to 2008. The difference corresponds to 3.6% of the area in 2005.

| Years | Vineyards and olive groves (ha) |
|---|---|
| 2005 | 2934.840 |
| 2008 | 2829.760 |
| Difference (2005 - 2008) | 105.080 |

method that can be used for this purpose is the cokriging, an optimal method that has been utilized in numerous applications (Cocco et al., 2006).

This method allows the use of two or more variables to enhance the precision of predictions, where the values of one variable do not depending only on its nearby values, but on the values of other variables at nearby locations (Wendy and Gimpel, 2006).

These further variables (the so called covariant variables) are the attributes matrix of the fields of the "fragricoltura" layer. Best results for data estimation were obtained when "trendcolt" and "trendurb" matrix fields were used as co-variables. The objective of cokriging is to predict the value of land agriculture loss from the second auxiliary variable obtained from urban trend ("trendurb"). These interpolated values are shown in color in Figure 3.

The output data set, from the aforementioned investigation, agrees with the previously obtained results. It is worth noting that the orange-red of the polygons of the agricultural parcels indicates those in danger of disappearance. Furthermore, to assess the quality of the trend data set, a comparison was made with a satellite image VHR Kompsat 2. This image, dates back to the 7th of August 2008, was geo-referenced, pan-sharpened and then, processed as described earlier. There is a good agreement between the trend computed with the data of the year 2005 and the observed situation in 2008. As a matter of fact, it can be inferred from Table 1. Where it can be seen that the urban sprawl phenomenon has had a major impact on the olive-tree cultivations. For the entire DOC area, Figure 4 and the Table 2 show the amount of missing cultivations.

## Conclusion

In this work, the satellite images were used only as a basis to create vector polygons and the subsequent analyses have focused on GIS methodologies. This is because a large vector database was already available from other previous projects, but this does not mean that it is not possible to apply the same method of analysis with classification of satellite images.

The method used for the evaluation of the API index is very easy to apply, but in order to perform this assessment with a high degree of accuracy, it is essential to have many data, respectively for the municipalities or different territories. The model applied has allowed the synthesis of the environmental situation of municipalities of a region, through the quantification of factors that may affect the phenomenon of land use changes. This type of analysis could be used by local authorities to perform simulations or estimates of environmental impact, and so become an interesting tool for planning. The model is comparative, in that the indicators were calculated on a scale from 1 to 5 and were specially designed for the survey area. In other cases and with an increased number of components, the scale and subjective weights that are to be applied to the index may vary. The proposed approach with GIS geostatistical methods in this case was used to calculate an index of innovative space that was useful for monitoring the phenomenon of urban sprawl.

This model was set up and tested successfully in the Frascati area, near Rome/Italy, and the results of these investigations provided evidence of a critical situation for both rural soil conservation and for the typical Frascati DOC wine production.

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## REFERENCES

Bacchus Project. http://www.esa.int/esapub/bulletin/bulletin123/bul123e_cheli.pdf

Batty M (1976). Urban Modelling, casa.ucl.ac.uk.

Batty M, Jiang B (1999). Multi-agent simulation: new approaches to exploring space-time dynamics in GIS- eprints.ucl.ac.uk.

Biondi M, Corridore G, Romano B, Tamburini P, Tetè P (2003). Evaluation and planning control of the ecosystem fragmentation due to urban development. ERSA Congress. August, Jyvaskyla, Finland.

Bresso M, Russo R, Zeppetella A (1990). Analisi dei progetti e valutazione di impatto ambientale. Franco Angeli Milano.

Cocco, A, Cossu QA, Erre P, Luciano P, (2006). Applicazioni geostatistiche e di tecnologie GIS per l'analisi delle fluttuazioni spaziali di Lymantria dispar (Lepidoptera Lymantriidae). 9° Convegno nazionale di agrometeorologia. AIAM 2006. Torino, giugno 6-8.

Eurostat (2008). L'agriculture dans l'Union européenne- Informations statistiques et économiques tab. 4.6.1.1 Vin.

Espon Project (2006). From http://www.espon.eu/main/Menu_Projects/Menu_ESPON2006Projects/

Fusco L, Loret E, Minchella A, Antunes J (2004). Il Progetto BACCHUS, una applicazione di tecniche avanzate per il rilevamento e la gestione di superfici vitate. 8° Conferenza Nazionale ASITA - GEOMATICA Fiera di Roma.

Herold M, Goldstein NC, Clarke KC (2003). Remote Sensing of Environment. eo.uni-jena.de.

Ioannilli M, Ambrosanio M (2006). Significato ed utilizzabilita' delle misure sullo stato dell'ambiente: l'esigenza di un nuovo approccio multidisciplinare. 16th Meeting of the Italian Society of Ecology. Viterbo, Civitavecchia

ISTAT (1992). Compendio Statistico Italiano, Roma

Loret E (2010). Estimation of increasing urbanization trend in the Frascati DOC wine area: a geostatistical analysis approach. - Tor Vergata University, PhD Thesis.

Martini A (1883). Manuale di metrologia. Loescher Torino . Ed. digitale a cura di Guido Mura, Milano. Biblioteca Nazionale Braidense 2003.

Romano B (2004). Environmental fragmentation tendency: the sprawl index ERSA Aug. 2004, Porto, Portugal.

Savitch H (2000). Dreams and Realities: Coping with Urban Sprawl", 19 Virginia Environ. Law J., pp. 333-342

Scott DW (1992). Multivariate Density Estimation. Theory, Practice and Visualization. New York: Wiley.

Silverman BW (1986). *Density Estimation*. London: Chapman and Hall.

Tempesta G, Fiorilo M, Ciolfi G, Agresta M, Casadei G (2007). Analisi del sistema vitivinicolo Laziale: passato, presente, tendenza. Rivista di Viticoltura ed Enologia, 60: 4.

Wendy TC, Gimpel JG (2006). Prospecting for (campaign) gold. Am. J. Pol. Sci., 51: 2(2007) 255-268.