



XVIIth World Congress of the International Commission of Agricultural and Biosystems Engineering (CIGR)

Hosted by the Canadian Society for Bioengineering (CSBE/SCGAB)
Québec City, Canada June 13-17, 2010



REMOTE SENSING AND GIS FOR RURAL/URBAN GRADIENT DETECTION

C. R. FICHERA¹, G. MODICA¹, M. POLLINO^{1,2}

¹ C.R. FICHERA, Mediterranean University of Reggio Calabria, Department of Agroforestry and Environmental Sciences and Technologies (DiSTaFA) – Località Feo di Vito – 89122 Reggio Calabria (Italy), cr.fichera@unirc.it.

¹ G. MODICA, giuseppe.modica@unirc.it.

² M. POLLINO, ENEA - National Agency for New Technologies, Energy and Sustainable Economic Development - “Earth Observation and GIS Unit”. Casaccia Research Centre - Via Anguillarese 301, Rome (Italy). maurizio.pollino@enea.it.

CSBE101486 – Presented at the 8th World Congress on Computers in Agriculture (WCCA) Symposium

ABSTRACT Identifying and mapping land cover/land use (LC/LU) and its change is one of the most important topics in remote sensing since this is the source of a wide range of environmental information about landscape changes, which is essential for an effective sustainable land planning and management. In this framework, a case study has been conducted in the area of Avellino (Southern Italy) by means of remote sensing techniques in combination with GIS and landscape metrics. A multi-temporal set of remote-sensed data has been used: aerial photos (surveys: 1954, 1974, 1980, 1990), Landsat images (MSS 1975, TM 1993, ETM+ 2000 and 2004) and digital aerial orthophotos (1994, 2000 and 2006). In order to highlight the temporal dynamics of changes, the study has integrated temporal trend analysis and landscape metrics and focussed on the urban-rural gradient. First, aerial photos have been interpreted and satellite images have been classified: the result has been a map of LC/LU changes during the last fifty years. This has allowed the characterization of landscape patterns through significant indices, in order to understand the changes therein, especially along the urban-rural fringes. This study has shown that LC/LU pattern and its change are linked to both natural and social processes whose driving role has been clearly demonstrated in the case study: after the disastrous Irpinia earthquake (1980), the local specific zoning laws and urban plans have significantly addressed landscape changes.

Keywords: Land cover change, Remote sensing, Landscape metrics, Gradient analysis.

INTRODUCTION One of the most important topics in Remote Sensing (RS) is directly linked to its capability to identify and map Land Cover/Land Use (LC/LU) and to detect their spatial and temporal change (Change Detection). Today, RS is the main source of a wide range of environmental information about landscape and its changes, which is essential for an effective sustainable land planning and management. Moreover, RS has proved to be much better than traditional procedures for LC/LU mapping and monitoring, in terms of cost effectiveness and timeliness in the availability of information over larger areas. The main goal of the study described in this paper is to process and analyze a

multi-temporal image dataset in order to identify the LC changing pattern during a fifty-year period (1954÷2004) and, consequently, understand the changes within an area of interest, especially along the urban-rural fringes. In particular, the development of urban areas transforms the landscape life style from rural into urban and leads to functional changes, from a morphological and structural point of view (Antrop, 2000; 2004). The development of cities has always been driven by the population growth: urban development and agriculture compete for the same land and, actually, over the last few years, the development of cities has typically taken place on lands formerly used for agricultural purposes. Just to mention a few data, the amount of land consumed by urban areas and associated infrastructures throughout Europe was about 800 km²·a year⁻¹ between 1990 and 2000 (EEA, 2006). This paper reports a case study conducted in the area of the Province of Avellino, in the Campania region (Italy).

THE STUDY AREA The Province of Avellino is characterized by many small towns and villages scattered across the Province. Its capital city Avellino is one of the only two towns with over 20000 inhabitants. Avellino (40°54'55"N 14°47'23"E, 348 m a.s.l., 42 km NE of Naples, Total population: 56700) is situated in a plain called “*Conca di Avellino*” and surrounded by mountains: *Massiccio del Partenio (Monti di Avella, Montevergine e Pizzo d’Alvano)* NW and *Monti Picentini* SE. Due to the Highway A16 and to other major roads, Avellino also represents an important hub on the road from Salerno to Benevento and from Naples.

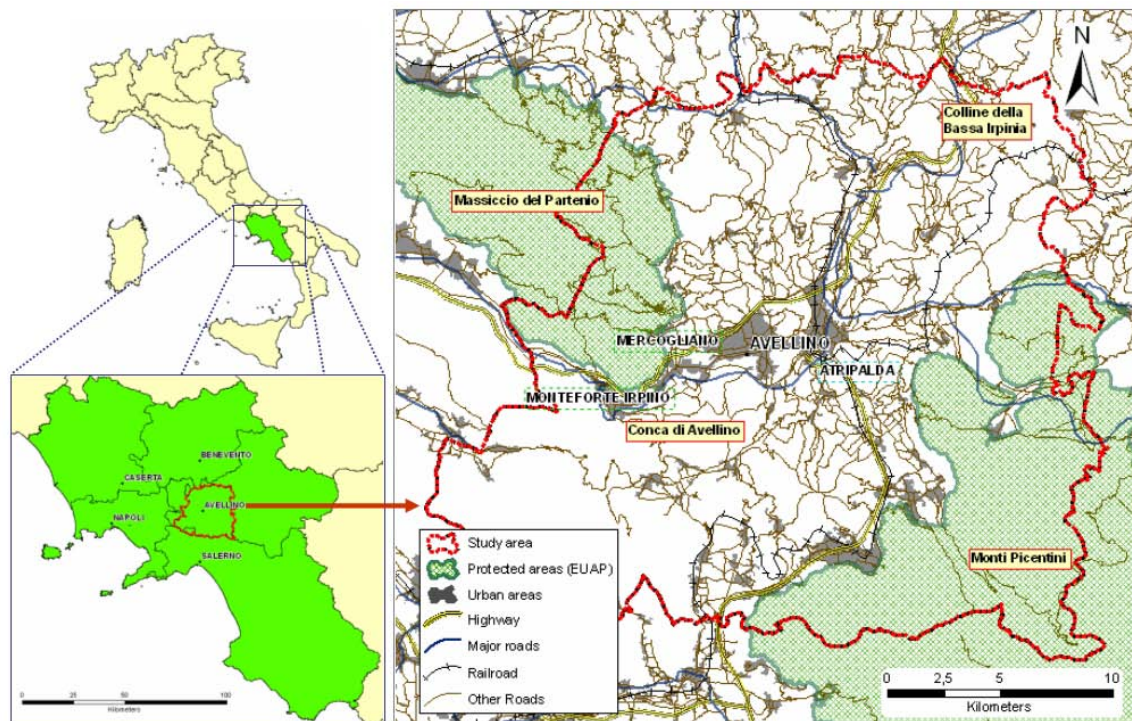


Figure 1. Geographic location of the study area “Conca di Avellino”, South of Italy.

Avellino has suffered from seismic activity throughout its history and was struck hard by the disastrous Irpinia earthquake of 23 November 1980. Measuring 6.89 on the Richter Scale, the quake, centred on the village of Conza, killed 2914 people, injured more than 80000 and left 280000 homeless. Towns in the province of Avellino were hardest hit and,

during the last thirty years, the Italian Government has spent around 30 billions Euros on reconstruction. As a consequence of the earthquake and in order to regulate the reconstruction activities, several specific acts, decrees, zoning laws and ordinances have been issued: the first was the Law n. 219/1981, which entrusted the Campania Region with the coordination of the activities and the damaged Municipalities with urban planning. Since 2006 the urban planning issues of Avellino and of its neighbouring areas have been regulated by two instruments: P.I.C.A. (Italian acronym that stands for Integrated Project for Avellino City) and P.U.C. (Urban Plan for Avellino Municipality)., The analysis has concerned the area of the *Conca di Avellino* (Figure 1), owing to its particular location as a plain between two natural protected areas: the Regional Park of Partenio (14870 ha) and the Regional Park of Picentini Mountains (62200 ha).

CHANGE DETECTION ANALYSIS In order to study and analyze LC changes within the area of interest, a multi-temporal set of remote-sensed data (Yuan et al., 2005; Lucas 2007) has been used: aerial photos (surveys: 1954, 1974, 1980, 1990), Landsat images (MSS 1975, TM 1993, ETM+ 2000 and 2004) and digital aerial orthophotos (1994, 2000 and 2006). RS data, opportunely processed and elaborated, can be really useful in change detection tasks to monitor the differences of LC at different times (Singh, 1989). Digital image-processing software ERDAS Imagine 9.3 (ERDAS, 2008) has been used to process, analyse and integrate the spatial data and geographic information so as to achieve the goals of this study.

The aerial photo dataset is composed of several surveys carried out during the last fifty years by “Istituto Geografico Militare Italiano” (I.G.M.I.), in its institutional role as national cartographic body. The past information on the LC has been extracted from black-white (BW) monoscopic aerial photographs taken in 1954 with a 1:35000 scale and a 1m spatial resolution. I.G.M. digital topographic maps (1:25000 scale) have been used as ground references for the georegistration of aerial photographs. The aerial photographs have been visually interpreted on-screen using direct (tone, texture, shape and pattern) and indirect (location and association) elements of recognition (Doygun, 2008). The photographs coming from the other surveys (1974-1980-1990-1996) have been used as a reference for the classification of the Landsat imagery selected for this study and described below. Moreover, to improve the above-mentioned elaborations and to support the visual interpretation tasks, a further dataset has been used: digital aerial orthophotos, dated 1996, 2000, 2006 and available - only for consultation - at the National Cartographic Portal (NCP, www.pcn.minambiente.it), the most important Italian GIS Server catalogue. The NCP (managed by the Italian Ministry for Environment, Land and Sea) allows the visualization and the use via GIS client of numerous geographic data (maps, cartographies, orthophotos, DTM, etc.). Table 1 shows the list of all the aerial photographs used and their main characteristics.

Another dataset of remote sensed images is represented by four Landsat images. The Landsat program strength stays in its continuity: since 1972 it has been a key milestone in RS technology and Earth observation (Franklin, 2001). During the last four decades, the Landsat data have provided a unique opportunity to investigate the territory and apply RS techniques at regional scales (Schowengerdt, 1997). The Landsat Multispectral Scanner (MSS) sensor provides image data with a spatial resolution of approximately 80 m, acquired across four spectral bands (i.e. visible and near-infrared). The Landsat Thematic Mapper (TM, launched in 1984) provides higher spectral, spatial, and radiometric

resolution data: spatial resolution of 30 m and 7 spectral channels, specifically designed to map vegetation type, soil moisture, and other key landscape features. A 15 m spatial resolution panchromatic band has been added to the Landsat Enhanced Thematic Mapper (ETM+). Overall, the availability of such a kind of data is very important nowadays for historical change detection studies and to generate maps for urban/suburban and natural environments (Jensen, 2000). The Landsat scenes used are listed in Table 2, which also shows their main characteristics.

Table 1. List of aerial collected for the study area.

Year	Frame data	Flight data	Source
1954	Sheet n° 185 Strip/Frames: 121 / 3803 3804 3805 3806 Strip/Frames: 122 / 4595 4596 4597 4598 Format: Digital – 600dpi	Height: 6000 m Scale: 1:35000	Istituto Geografico Militare Italiano (I.G.M.I.) http://www.igmi.org
1974	Sheet n° 185 Strip/Frames: XIII A / 823 824 825 Strip/Frames: XIV A / 850 851 852 Format: Analogical 23x23 cm	Height: 2580 m Scale: 1:16000	
1980	Sheet n° 185 Strip/Frames: 11 / 526 527 528 Strip/Frames: 12 / 604 605 606 Format: Analogical 23x23 cm	Height: 2600 m Scale: 1:15000	
1990	Sheet n° 185 Strip/Frames: 10 / 23 24 25 Strip/Frames: 11 / 103A 104A 105A Format: Digital – 600dpi	Height: 6400 m Scale: 1:35000	
1996	Sheet n° 185 Strip/Frames: 64 / 1072 1073 1074 Strip/Frames: 66 / 1056 1057 1058 Format: Digital – 600dpi	Height: 6800 m Scale: 1:42000	
1994	B/W Aerial Orthophoto via GIS Server catalogue (only for consultation)		
2000	Colour Aerial Orthophoto via GIS Server catalogue (only for consultation)		
2006	Colour Aerial Orthophoto via GIS Server catalogue (only for consultation)		

Other ancillary spatial data have been also included in order to support the classification and change detection procedures: basic datasets (administrative boundaries, hydrography, road network, railways, protected areas, etc.) and 1:5000 scale digital cartography. All layers, aerial photos and satellite images have been georectified in UTM-33N projection, Datum WGS84.

Starting from the above-described dataset of co-registered multi-temporal images, the process of digital change detection, which has been developed, has allowed to determine and describe changes in LC/LU by means of classification procedures and photo-interpretation tasks between two fundamental dates: 1954 and 2004. The approach, which has been followed (Lunetta, 1998), is based on specific data processing requirements:

- Geometric and radiometric corrections;
- Data normalization;
- Image classification and thematic accuracy assessment.

Geometric registration has been implemented in order to decrease the distortion effects typical of remote sensed data. Therefore, the registration of this multi-temporal dataset has been essential for change detection to reduce pixel errors that could be interpreted as LC change. Radiometric correction and data normalization tools have been used to take into account the variations in solar illumination conditions, the atmospheric scattering and absorption: in fact, those factors could cause differences in radiance values unrelated to the reflectance of land cover (Song et al., 2001). Seasonal effects often lead to errors in change detection: imagery acquired only during the summer period has been used in this study, thus avoiding the uncertainty of inter-annual variability.

Table 2. List of satellite images collected for the study area.

Satellite data	Date	Spatial resolution	Source
Landsat MSS (WRS-1, Path 203, Row 032)	1975-07-15	57 m	Global Land Cover Facility (GLCF) http://glcf.umiacs.umd.edu
Landsat TM (WRS-2, Path 189, Row 032)	1993-08-23	30 m	
Landsat ETM+ (WRS-2, Path 189, Row 032)	2000-08-02	28.5 m – 14.5 m	
Landsat ETM+ (WRS-2, Path 189, Row 032)	2004-06-10	28.5 m – 14.5 m	

To perform image classification, using supervised approaches, four classes have been defined: Urban, Woodland, Cropland and Grassland/Pasture. Other potential classes, like Bare surface or Water body, have not been included because they have not been considered very significant within the study area. In general, supervised classification requires prior knowledge of the ground cover in the study area and is, therefore, a more intuitive method for land-cover change mapping. With the supervised approach, calibration pixels are selected and associated statistics are generated for the classes of interest. A congruous number of training samples has been selected through reference data and ancillary information. Then, using ERDAS Imagine 9.3, the supervised Maximum Likelihood Classification (MLC) algorithm, which provides the best results from remotely-sensed data if each class has a Gaussian distribution (Bolstad and Lillesand 1991), has been applied to each image. Finally, a 3×3 majority filter has been applied to the classified LC data in order to reduce the “salt-&pepper” effect (Lillesand and Kiefer, 1999): this operation has allowed to make the image look good and to smooth out the classes, giving a better appearance. Accuracy assessment is critical for LC maps

derived from satellite RS data. In order to evaluate the user's and the producer's accuracy, a confusion matrix has been applied to the classified images (Congalton, 1991; Congalton and Green, 2009). In particular, for the ETM+ image of 2004, the LC class assigned to 331 random pixels was visual compared with the equivalent area in the aerial orthophoto of the same period. The overall accuracy of the land-cover map has been 84.6%.

Two different LC maps have been produced from the classified image deriving from the Landsat ETM+ 2004 scene and from the results of the visual interpretation of the aerial frames acquired in 1954, respectively. That of 2004, originally in raster format, has been converted into the shapefile *.shp* vector format (ESRI, 2006), whereas that of 1954 has been directly produced in shapefile format. To determine the changes in LC in different years, the 1954 map has been compared with that of 2004, by means of the "Analysis Tools" of ArcGIS Desktop 9.2 (ESRI, 2006). Such a kind of approach has been chosen to better compare data from different sources, dates and formats. One of the advantages is to make directly available the tables containing the spatial information of each class (area, perimeter, etc.) and the information about amount, location and nature of change. Figure 2 shows the global dynamics of LC transformations occurred during the period 1954÷2004 and detected using the above-described approach.

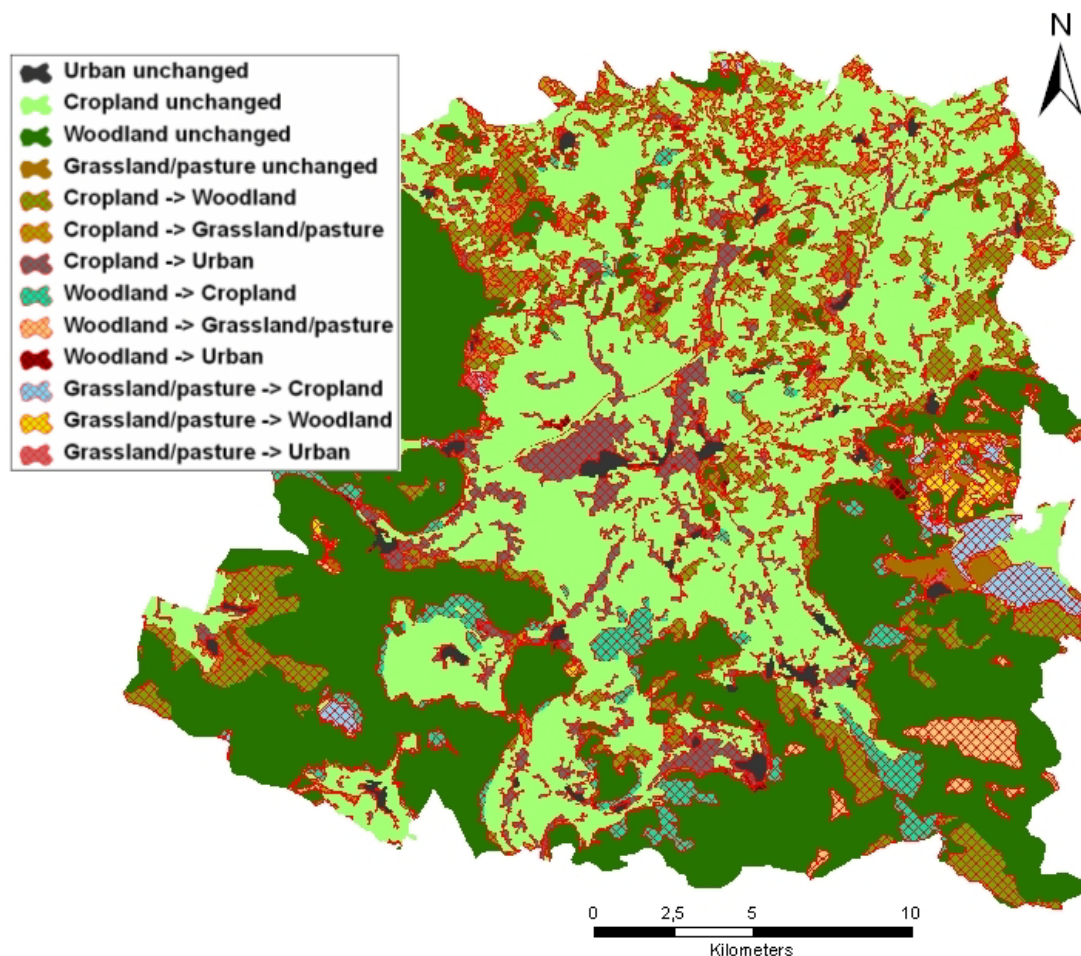


Figure 2. Map showing LC changes (1954÷2004) in the study area.

Table 3 summarizes the relative statistics. The area values (in hectares) reported along the diagonal are indicative of the unchanged LC types; the other cells contain the measurement of the areas that have suffered a transformation from a LC type to another class. The column on the right sums up 1954 LC areas, while the last line sums up the 2004 LC areas.

Table 3. Total LC change for the defined land cover types: dynamics from 1954 to 2004 (Area in ha).

<i>To</i> <i>From</i>	<i>Urban</i>	<i>Grassland/pasture</i>	<i>Cropland</i>	<i>Woodland</i>	LC types subtotals [1954]
<i>Urban</i>	900.97	-	-	-	900.97
<i>Grassland/pasture</i>	75.12	354.37	781.98	411.30	1622.77
<i>Cropland</i>	3786.87	1091.66	19409.16	7420.54	31708.23
<i>Woodland</i>	162.11	686.50	2246.49	20136.09	23231.20
LC types subtotals [2004]	4925.07	2132.53	22437.63	27967.93	<i>Total area:</i> 57463.16

Landscape Metrics analysis The analysis of spatial structures and patterns is central in landscape ecology and planning; landscape metrics (also referred to as landscape indices or as spatial metrics) are one of the hot topics of modern landscape ecological research (Uuemaa et al., 2009). The Landscape or spatial metrics, which have been used to quantify the spatial patterning of the LC patches and LC classes of the study area, can be defined as quantitative and aggregate measurements showing spatial heterogeneity at a specific scale and resolution (Herold et al., 2003). The basis of the spatial metric calculation is a thematic map representing a landscape comprised of spatial patches categorized in different patch classes. In particular, spatial metrics have the capability to describe the composition and spatial arrangement of the land covers in a landscape. Therefore, they can be used to describe landscape patterns and structures. When applying spatial metrics, the spatial unit used is called a patch, defined as a relatively homogeneous area that differs from its surroundings (Forman, 1995). Our approach combines remote sensing and landscape metrics to understand spatial-temporal patterns of LC, like urban-rural gradient analysis (Luck and Wu, 2002). The two LC maps, produced in 1954 and 2004 respectively, are shown in Figures 3-A and 3-B. To detect the gradient of landscape patterns, a series of analyses have been conducted along two transects (W-E and SW-NE directions) outlined within the study area and centred on the main settlement of Avellino (Figure 3): each transect is formed by one row and subdivided into eleven 2 km x 2 km blocks. In order to detect the spatio-temporal dynamics of the landscape mosaic of the study area, a set of landscape metrics has been chosen and calculated for the two defined transects. The software package FRAGSTATS raster version 3.3 (McGarigal et al., 2002) has been used to calculate the selected

landscape metrics with the patch neighbour 8-cell rule option both at landscape and class level. The results of the metric analysis are dependent upon the input pixel size; in this study, the pixel size of 30 m has been chosen. After Cushman et al. (2008), the following landscape metrics have been selected in this study: Contagion (CONTAG), LSI (Largest Shape Index) SIDI (Simpson's Diversity Index) and SIEI (Simpson's Evenness Index) in order to take into account the contagion/diversity component; LPI (Largest Patch Index) and COHESION index for large patch dominance component; Patch Richness Density (PRD), NP (Number of Patches) and Interspersion/Juxtaposition Index (IJI).

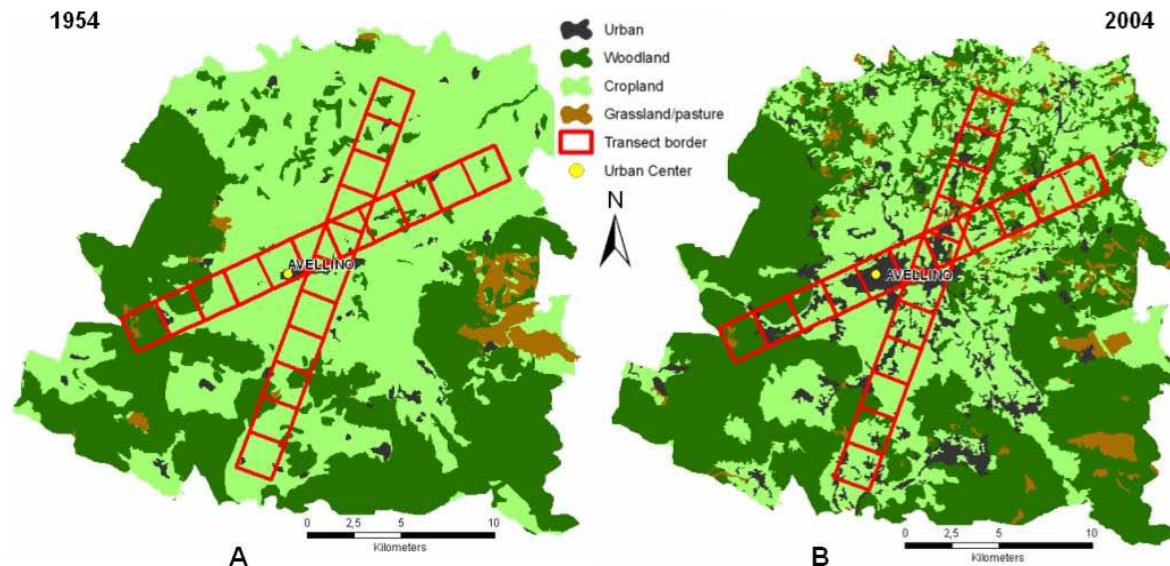


Figure 3. LC maps for 1954 (A) and 2004 (B) and location of the two transects (eleven 2 km x 2 km blocks per each transect) across the study area.

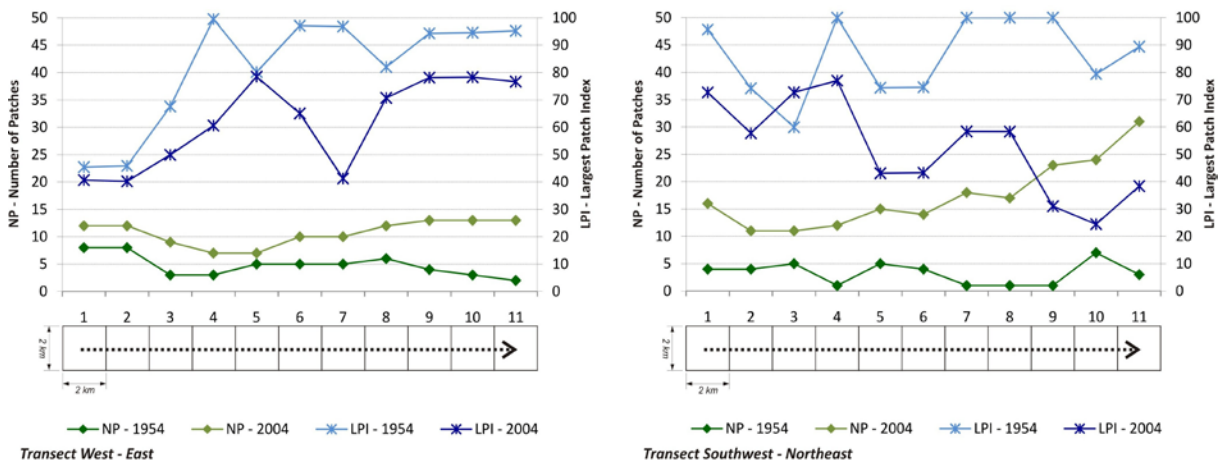


Figure 4. Spatio-temporal changes in the blocks along the W-E and the SW-NE transect for NP and LPI metrics in the 1954-2004 period.

This paper presents two of the landscape metrics calculated: the Number of Patches (NP) and the Largest Patch Index (LPI). NP is a simple measure of the extent of subdivision or fragmentation of the patch type. In particular, NP illustrates the diffused sprawling development and the fragmentation of rural areas. LPI quantifies, at the class level, the percentage of total land area comprised by the largest patch and is a simple measure of the dominance of a LC type. Figure 4 shows the trends of NP and LPI for each transect and for each of the two years taken into account (1954 and 2004).

CONCLUSIONS This study has demonstrated that patterns of LC/LU have been identified and characterized using a multi-temporal dataset of remote sensed images and landscape metrics. As reported in Table 3, the results of the RS images classification indicate that urbanization has significantly modified the LC of the study area, with significant land conversions. During the five decades analyzed, the Urban LC type has almost quintupled (passing from 1.6% to 8.6% of the total area of study), mostly at the expense of the Cropland LC type, which has suffered the major effects of the expansion of the built-up areas. Woodland and Grassland/Pasture LC types have, instead, remained relatively unchanged. One of the reasons of that conversion is the proximity of Avellino to other urban centres, as Atripalda, Mercogliano and Monteforte Irpino (all of which have over 10.000 inhabitants). All those towns are actually in a territorial continuity with the main settlement of Avellino and this interaction gives rise to the urban sprawl phenomena which, during the last years, has interested the area. The population growth has driven urban expansion: Avellino inhabitants were 19.929 in 1861, 24.710 in 1911, 41.825 in 1961 and 56.862 in 1981 (source: ISTAT, Italian National Institute of Statistics, www.istat.it). Nevertheless, between 1981 and 2001, it is possible to notice a population decrease, due to the transfer of many people from the urban centre of Avellino to the above-mentioned neighbouring towns: the consequence is an “extended” urban area, with around 120.000 inhabitants. Another significant incentive to the urban expansion has come from the indications of P.I.C.A. and P.U.C. plans, both placing the areas devoted to the industrial use in the northern zone of Avellino. Therefore, urban sprawl has principally expanded along two directions: the first is the SW-NE one, which coincides with the A16 Highway course and with the axis that connects Monteforte Irpino and Mecrogliano with Avellino; the second spans along the W-E direction and includes the new industrial estate of Avellino.

REFERENCES

- Antrop, M. (2000). Changing patterns in the urbanized countryside of Western Europe. *Landscape Ecology*, 15(3): 257-270.
- Antrop, M. (2004). Landscape change and the urbanization process in Europe. *Landscape and Urban Planning*, 67: 9-26.
- Bolstad, P. V., and T. D. Lillesand. 1991. Rapid Maximum Likelihood classification. *Photogrammetric Engineering & Remote Sensing*, 57: 67-74.
- Congalton, R.G. 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37 (1): 35-46.
- Congalton, R.G., and K. Green. 2009. *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices*. CRC Press Taylor & Francis Group, Boca Raton, FL.
- Cushman, S.A., K. McGarigal, and M.C. Neel. 2008. Parsimony in landscape metrics: Strength, universality, and consistency. *Ecological Indicators* 8 (2008): 691-703.
- Dewan A. M., and Y. Yamaguchi. 2009. Using remote sensing and GIS to detect and monitor land use and land cover change in Dhaka Metropolitan of Bangladesh during

- 1960-2005. *Environ. Monit. Assess.* 150: 237-249.
- Doygun H., H. Alphan, and K. D. Gurun. 2008. Analyzing urban expansion and land use suitability for the city of Kahramanmaraş, Turkey, and its surrounding region. *Environ. Monit. Assess.* (2008) 145: 387-395.
- EEA (European Environment Agency). 2006. Urban sprawl in Europe: The ignored challenge. EEA Report No. 10/2006, Copenhagen, Denmark.
- Environmental System Research Institute. 2006. ArcGIS™ Tutorial. ESRI, USA.
- ERDAS. 2008. ERDAS Imagine Field Guide™. ERDAS Inc., Vol. 1 & 2, USA.
- Forman, R.T.T. 1995. *Land Mosaics: The Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge, UK.
- Franklin, S.E. 2001. *Remote Sensing for Sustainable Forest Management*. Lewis Publishers, Boca Raton, FL.
- Herold M., N. C. Goldstein, and K. C. Clarke. 2003. The spatiotemporal form of urban growth: measurement, analysis and modeling. *Remote Sensing of Environment* 86 (2003) 286–302.
- Jensen, J.R. 2000. *Remote Sensing of the Environment: an Earth Resource Perspective*. Prentice Hall, Saddle River, NJ.
- Ji W, J. Ma, R. W. Twibell, and K. Underhill. 2006. Characterizing urban sprawl using multi-stage remote sensing images and landscape metrics. *Computers, Environment and Urban Systems* 30: 861–879.
- Lillesand, T. M., and R. W. Kiefer. 1999. *Remote Sensing and Image Interpretation*. New York: John Wiley and Sons.
- Lucas R., A. Rowlands, A. Brown, S. Keyworth, and P. Bunting. 2007. Rule-based classification of multi-temporal satellite imagery for habitat and agricultural land cover mapping. *ISPRS Journal of Photogrammetry & Remote Sensing* 62: 165–185.
- Luck, M., and J. Wu. 2002. A gradient analysis of urban landscape pattern: A case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecology*, 17(4): 327-339.
- Lunetta, R.S., and C.D. Elvidge, Eds. 1998. *Remote Sensing Change Detection: Environmental Monitoring Methods and Applications*. Taylor and Francis, London, 1998.
- McGarigal, K., S.A. Cushman, M.C. Neel, and E. Ene. 2002. FRAGSTATS: spatial pattern analysis program for categorical maps. Computer software program produced by the authors at the University of Massachusetts, Amherst. Available from <http://www.umass.edu/landeco/research/fragstats/fragstats.html>.
- Schowengerdt, R.A. 1997. *Remote Sensing: Models and Methods for Image Processing*. Second ed, Academic Press, San Diego.
- Singh, A. 1989. Digital Change Detection Techniques using Remotely Sensed Data. *International Journal of Remote Sensing*, Vol.10: 989- 1003.
- Song, C., C.E. Woodcock, K. Seto, M.P. Lenney, and S. Macomber. 2001. Classification and change detection using Landsat TM data: when and how to correct atmospheric effects. *Remote Sensing of Environment* 75: 230–244.
- Uuemaa, E., M. Antrop, J. Roosaare, R. Marja, and Ü. Mander. 2009. Landscape Metrics and Indices: An Overview of Their Use in Landscape Research. *Living Rev. Landscape Res.*, 3, (2009), 1.
- Yu X. J., and C. N. Ng. 2007. Spatial and temporal dynamics of urban sprawl along two urban–rural transects: A case study of Guangzhou, China. *Landscape and Urban Planning* 79: 96–109.

Yuan F., K. E. Sawaya, B. C. Loeffelholz, and M. E. Bauer. 2005. Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. *Remote Sensing of Envir.*, 98 (2&3): 317-328.