Taylor & Francis
Taylor & Francis Group

European Journal of Remote Sensing

ISSN: (Print) 2279-7254 (Online) Journal homepage: http://www.tandfonline.com/loi/tejr20

Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics

Carmelo Riccardo Fichera, Giuseppe Modica & Maurizio Pollino

To cite this article: Carmelo Riccardo Fichera, Giuseppe Modica & Maurizio Pollino (2012) Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics, European Journal of Remote Sensing, 45:1, 1-18, DOI: 10.5721/EuJRS20124501

To link to this article: http://dx.doi.org/10.5721/EuJRS20124501

Land Cover classification and change-detection analysis using multi-temporal remote sensed imagery and landscape metrics

Carmelo Riccardo Fichera[1], Giuseppe Modica[1] and Maurizio Pollino[1,2]*

[1]"Mediterranea" University of Reggio Calabria,
Department of Agroforestry and Environmental Sciences and Technologies (DiSTAfA)
Località Feo di Vito - 89122 Reggio Calabria (Italy)
[2]ENEA - National Agency for New Technologies, Energy and Sustainable Economic Development
"Earth Observations and Analyses" Lab (UTMEA-TER)
Casaccia Research Centre - Via Anguillarese 301, 00123 Rome (Italy)
*Corresponding author, e-mail address: maurizio.pollino@enea.it

Abstract

Remote Sensing (RS) data and techniques, in combination with GIS and landscape metrics, are fundamental to analyse and characterise Land Cover (LC) and its changes. The case study here described, has been conducted in the area of Avellino (Southern Italy). To characterise the dynamics of changes during a fifty year period (1954÷2004), a multi-temporal set of images has been processed: aerial photos (1954), and Landsat scenes (MSS 1975, TM 1985 and 1993, ETM+ 2004). LC pattern and its changes 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), specific zoning laws and urban plans have significantly addressed landscape changes

Keywords: Classification, Land Cover (LC) changes, Change-detection, Landscape metrics, Sustainable landscape planning, Avellino (Italy).

Introduction

Gather information about Land Cover (LC) changes is fundamental for a better understanding the relationships and interactions between humans and the natural environment. Remote sensing (RS) data have been one of the most important data sources for studies of LC spatial and temporal changes. In fact, multi-temporal RS datasets, opportunely processed and elaborated, allow to map and identify landscape changes, giving an effective effort to sustainable landscape planning and management [Dewan et al., 2009]. In particular, by means of the integration of RS and GIS techniques, it is possible to analyse and to classify the changing pattern of LC during a long time period and, as a result, to understand the changes within the area of interest.

As a matter of fact, GIS techniques are efficiently exploited to analyse the effects of various factors on LC changes: those factors include population density, terrain slope, proximity to roads, and surrounding land use. The availability of time-series dataset is essential to

European Journal of Remote Sensing - 2012, 45: 1-18
doi: 10.5721/EuJRS20124501

understand and monitor the urban expansion process, in order to characterise and locate the evolution trends at a detailed level. In fact, during the last three decades, satellite time series as Landsat images have been exploited in several studies [Masek et al., 2000; Yang and Lo, 2002; Yuan et al., 2005] to evaluate built-up expansion and to assess urban morphology changes. The main goal of those studies was the spatiotemporal analysis of LC dynamics, focusing on urban growth/sprawl phenomenon and loss of rural land. The term "sprawl" is often used to describe the awareness of an unsuitable development, as a disordered growth of urban areas [Sudhira et al., 2004]. Sprawl is the consequence of many individual decisions and among the possible causes of this phenomenon we can find population growth, economy and proximity to resources and basic facilities [Wilson et al., 2003].

Is well known that the development of the urban areas is able to transform landscapes formed by rural into urban life styles and to make functional changes, from a morphological and structural point of view [Antrop, 2000; 2004]. Historically, urban development and agriculture are competing for the same land: cities expansion has typically take place on former agricultural use. Just to mention some data, the amount of land consumed by urban areas and associated infrastructure throughout Europe was about 800 $km^2 \cdot year^{-1}$ between 1990 and 2000 [EEA, 2006]. Moreover, population outside central cities has grown faster than downtown areas in many developed regions, demonstrating a certain tendency of the outward expansion of urban areas [Angel et al., 2005]. In fact, several cities are quickly growing at their fringes, transforming the surrounding rural areas into dense industrial and commercial ones, or less dense suburban developments [Huang et al., 2009].

In particular, in Italian experience, it is possible to observe over the years an increase of the pressure on countryside due to land renting and displacement of some typical functions outside the cities [Murgante and Danese, 2011]. The consequence is a reversal trend of demographic relationships between urban and rural areas, if compared with the dynamics during the period after the Second World War, that was characterised by an high birth rate and the maximum migration from country to urban areas.

So, the development of *ad hoc* GIS and RS techniques is very helpful to analyse LC change and to understand the factors that are able to drive the dynamic processes of rural-urban land transformation.

Materials and methods

Description of the study area

The methodology here described has been developed taking into account a study area within the Province of Avellino, in the Campania region (Italy). This area is characterised by many small towns and settlements scattered across the Province. Its capital city Avellino (40°5'55"N 14°47'23"E, 348 m a.s.l., 42 km NE of Naples, Total population: 52,700) is situated in a plain called "Conca di Avellino" (Fig. 1) and surrounded by mountains: Massiccio del Partenio (Monti di Avella, Montevergine e Pizzo d'Alvano) on NW and Monti Picentini on SE. Due to the Highway A16 and to other major roads (S.S. 7 and S.S. 7bis), Avellino also represents an important hub on the road from Salerno to Benevento and from Naples.

Avellino was struck hard by the disastrous Irpinia earthquake of 23 November 1980. Measuring 6.89 on the Richter Scale, the quake killed 2,914 people, injured more than 80,000 and left 280,000 homeless. Towns in the province of Avellino were hardest hit and the Italian Government spent during the last thirty years around 30 billions of Euros on reconstruction. Consequently to the earthquake and to regulate the reconstruction activities, several specific acts, decrees, zoning laws and ordinances have been issued: the first one was the Law n. 219/1981 that entrusted the urban planning to the damaged municipalities, under the coordination of the Campania Region. From 2006 the urban planning issues of Avellino and neighbour areas are 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). Considering this general framework, the analysis here presented pertains to the *Conca di Avellino* area (extended 57,355 ha), in consequence of its particular location: a built-up area between the two natural protected zones of Regional Park of Partenio (14,870 ha) and Regional Park of Picentini Mountains (62,200 ha).

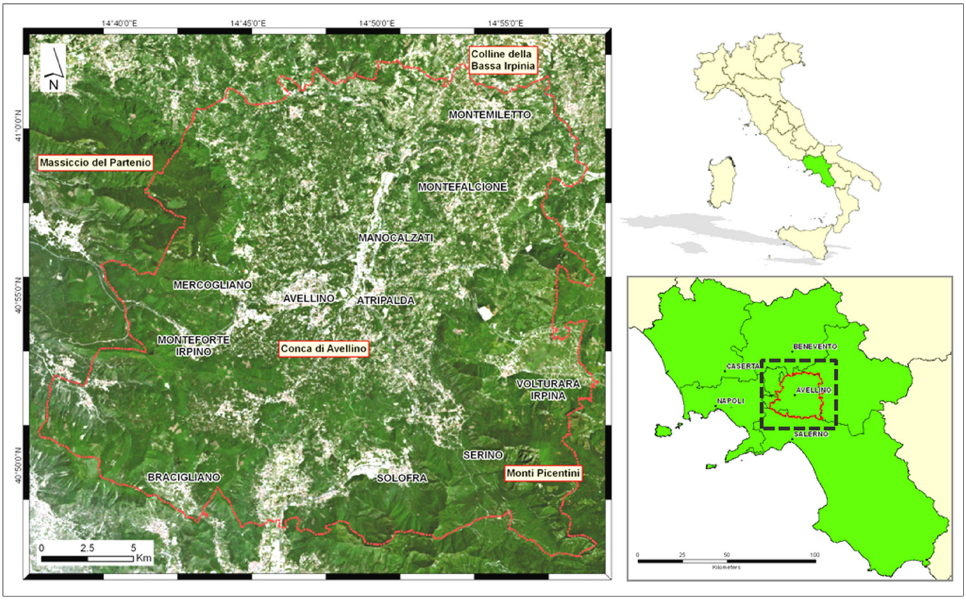


Figure 1 - Geographic location of the study area.

Land Cover Classification

A multi-temporal set of RS data of the area of interest has been used to study and classify LC [Yuan et al., 2005; Lucas, 2007]. This dataset included aerial photos (1954, 1974 and 1990 surveys carried by "Istituto Geografico Militare Italiano", IGMI), Landsat images (MSS 1975, TM 1985 and 1993, ETM+ 2004) and digital aerial orthophotos (1994 and 2006).

Digital image-processing software ERDAS Imagine (v. 9.3 and v. 2010) has been used to process, analyse and integrate the spatial data and geographic information so as to achieve the above mentioned goals.

The earliest information about LC has been extracted from black-white (BW) monoscopic aerial photographs taken in 1954, with 1:35,000 scale and 1 m spatial resolution (acquired by IGMI), which have been visually interpreted on screen, by way of direct (tone, texture, shape and pattern) and indirect (location and association) elements of recognition [Lillesand et al., 2003; Gomarasca, 2009]. The resulting map has a geometric resolution comparable whit the one of topographic cartography of IGMI (1:25,000 scale), also used as reference. 1974 and 1990 frames have been, instead, used as a reference for the Landsat classification procedure, following described. Furthermore, digital aerial orthophotos dated at 1994 and 2006 have been also used for the same purpose. Those latter data are available - only for consultation and visualization - at the National Cartographic Portal (NCP, www.pcn.minambiente.it, a GIS Server catalogue, managed by Italian Ministry of the Environment, Land and Sea). Further, all the aerial photos, satellite images and maps produced have been georeferenced in UTM-33N projection, Datum WGS84, using the 2006 orthophotos as geometric reference. In Table 1, all the aerial photography used and their main characteristics are listed.

Table 1 - List of aerial photographs and digital aerial orthophotos collected for the study area.

Frame data	Date	Flight data	Source
Sheet n° 185 Format: Digital – 600dpi	September 1954	Height: 6,000 m Scale: 1:35,000	Istituto Geografico Militare (IGMI) www.igmi.org
Sheet n° 185 Format: Analogical 23x23 cm	May 1974	Height: 2,580 m Scale: 1:16,000	
Sheet n° 185 Format: Digital – 600dpi	June-Sept. 1990	Height: 6,400 m Scale: 1:35,000	
B/W digital aerial orthophotos - GIS Server catalogue (only for consultation)	August 1994	Spatial res. 1.0 m	Italian Ministry of the Environment, Land and Sea National Cartogr. Portal www.pcn.minambiente.it
RGB colour digital aerial orthophotos - GIS Server catalogue (only for consultation)	May-June 2006	Spatial res. 0.50 m	

Then, to obtain information about LC for the 1975÷2004 interval, four Landsat images have been processed and classified: their main characteristics are summarised in Table 2.

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)	1985-06-14	30 m	USGS Global Visualization Viewer http://glovis.usgs.gov/
Landsat TM (WRS-2, Path 189, Row 032)	1993-08-23	30 m	Global Land Cover Facility (GLCF) http://glcf.umiacs.umd.edu
Landsat ETM+ (WRS-2, Path 189, Row 032)	2004-06-10	28.5-14.5 m	Global Land Cover Facility (GLCF) http://glcf.umiacs.umd.edu

The Landsat program strength stays in its continuity: since 1972 its data have provided a unique opportunity to investigate the territory and apply RS techniques at regional scales

[Schowengerdt, 1997]. In general, the availability of such data is very important nowadays for historical change detection studies and to generate maps for urban/suburban and natural environments [Jensen, 2000].

The approach, which has been followed [Lunetta and Elvidge, 1998], is based on the following processing procedure. First of all, the multi-temporal dataset has required a geometric registration, in order to decrease the distortions effects and to reduce pixel errors that could be interpreted as LC changes.

Subsequently, Landsat images have been atmospherically corrected by means the specific software tool embedded in ERDAS Imagine (based on the ATCOR algorithm, http://www.geosystems.de/atcor/index.html), in order to take into account the variations in solar illumination conditions, the atmospheric scattering and absorption. Those factors, in fact, could cause differences in radiance values unrelated to the reflectance of land cover [Song et al., 2001]. To mitigate the seasonal effects, which often lead to errors in change detection, have been used only imagery acquired during the summer period, avoiding the uncertainness of inter-annual variability. Next task was image classification. Using the supervised approaches, four classes have been defined: *Urban, Woodland, Cropland* and *Grassland/Pasture*. A congruous number of training samples has been selected through reference data and ancillary information.

Then, to each image has been applied the supervised *Maximum Likelihood Classification* (MLC) algorithm, more suitable when each class defined has a Gaussian distribution [Bolstad and Lillesand 1991]. Finally, a 3×3 majority filter has been applied to the classified LC data, to reduce the “salt&pepper” effect [Lillesand and Kiefer, 1999].

In order to evaluate the user’s and the producer’s accuracy, a confusion matrix was applied to the classified images [Congalton, 1991; Congalton and Green, 2009]. In particular, for each Landsat image, the LC class assigned to 256 pixels (selected using a stratified random sample) was visual compared with the equivalent area in the aerial frames (IGMI photos and/or NCP orthophotos) closer to the same period. The overall accuracy values of each classified image are reported in Table 3.

Table 3 - Accuracy assessment for the classified images

Reference Year	Classified image	Overall Classification Accuracy	Overall Kappa Statistics
1975	Landsat MSS	86.72%	0.7478
1985	Landsat TM	82.42%	0.6863
1993	Landsat TM	83.20%	0.7060
2004	Landsat ETM+	95.70%	0.9285

Finally, five different LC maps have been produced (Fig. 2). The 1975, 1985, 1993 and 2004 maps, originally in raster format (30 m pixel resolution), have been converted into the shapefile (*.shp) vector format, whereas the 1954 one has been directly produced into the shapefile format. This format is more suitable for the change-detection procedures successively carried out.

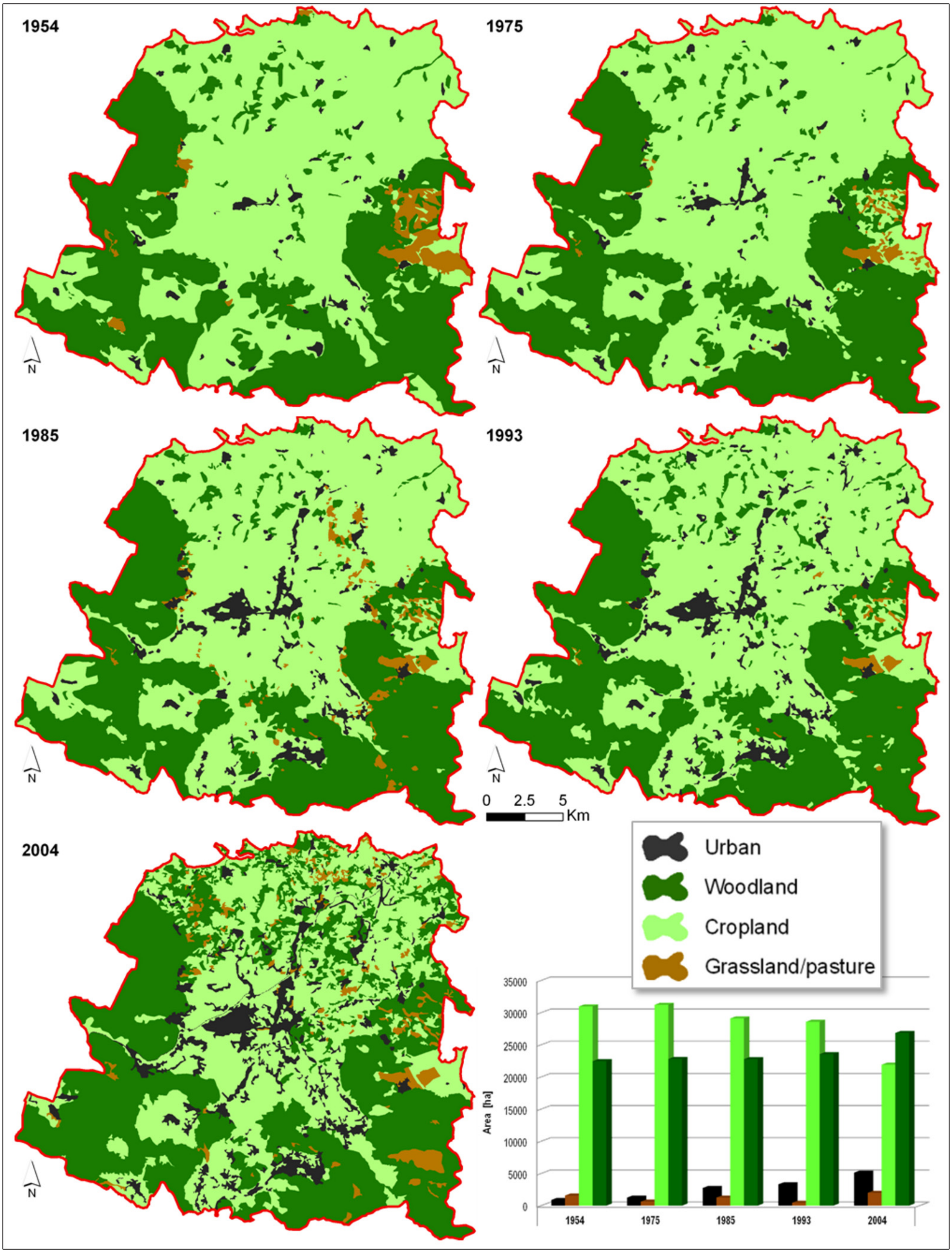


Figure 2 - LC maps for the five time periods define

Change Detection

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]. Thus, starting from the above described dataset of multi-temporal classified images, the process of digital change detection developed has allowed to determine and describe changes in LC between four fundamental intervals: 1954÷1975, 1975÷1985, 1985÷1993 and 1993÷2004.

There are many methods of change detection available [Lu et al., 2004] and each has variations depending on the imagery type, final purpose for the change image and the type of change to be detected. In the case-study here described, the methodology followed has been the "Post-classification comparison" [Jensen et al., 1987; Dimyati et al., 1996; Ward et al., 2000]. Such approach allows to determine the difference between independently classified images from each of the dates in question and it is the only method in which "from" and "to" classes can be calculated for each changed pixel. This method offers the advantage to allow the creation and the update of GIS databases, as class/categories are given, and quantitative values of each class can be determined.

Jointly with "Post-classification comparison", a GIS approach [Taylor et al., 2000] has been combined, to efficiently integrate LC maps and to quantitatively reveal the change dynamics in each category. The advantage of GIS techniques it's not only linked to exploitation of database capabilities, but also to the ability to manage different LC maps by means of typical vectorial operators like "intersect" and "union", in order to easily evaluate the amount of change [Petit and Lambin, 2001].

Such approach, comparing the LC data, has allowed 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. Hence, comparing each classified map with the successive, it has been possible to determine the changes in LC at different years from 1954 to 2004. In addition to ERDAS Imagine, ESRI ArcGIS Desktop (v. 9.3) has been used to analyse and integrate LC maps and extract the GIS layers describing changes and dynamics of land cover [Fichera et al., 2011].

Subsequently, in order to perform the accuracy assessment on the change detection procedures, has been followed the approach proposed by Congalton and Macleod [1994], in which the error matrix normally used for the single-date classification is purposely modified. This new matrix has the same characteristics as the single-date classification error matrix, except that it also assesses errors in changes between two time periods and not simply a single classification. For example, considering the classes defined in this case-study, the single classification matrix is of dimension 4x4, whereas the change detection error matrix is 16x16 (the size of the number of categories squared): in fact this matrix concern a change between two different maps generated at different times in assessing change detection (between time 1 and time 2) and not simply a single classification [Congalton and Green, 2009]. Moreover, the change detection error matrix has been simplified by collapsing into a *no-change/change* error matrix [Congalton and Green, 2009]: the upper left box reports the areas that did not change in either the classification or reference data; the upper right box indicates the areas that the classification detected no change and the reference data considered changed. Those collapsed *no-change/change* error matrices have been produced for the reference periods 1975÷1985, 1985÷1993 and 1993÷2004 (LC maps extracted from Landsat data) and the relative values are reported in Table 4.

Finally, the previous described results of change detection task have been combined to produce the transition matrices with LC change by time for every reference periods. The quantification of change for the categories analysed is given in Table 5, where are reported the relative statistics, aggregated for each class. The values (in hectares) reported along the diagonal express the area of the unchanged LC types; the other cells contain the measurement of the areas that have bore a transformation from a LC type to another class. The column on the right sum up the LC areas at the beginning of all the intervals examined, while the last row sums up the LC areas at the end.

Table 4 - ***No-change/change*** **error matrices for the change-detection technique.**

1975÷1985				**1985÷1993**				**1993÷2004**			
	NC	C	Total		NC	C	Total		NC	C	Total
NC	**181**	56	237	NC	**179**	54	233	NC	**188**	34	222
C	6	**12**	18	C	9	**14**	23	C	14	**20**	34
Total	187	68	**255**	Total	188	68	**256**	Total	202	54	**256**
Overall accuracy			*75.7%*	*Overall accuracy*			*74.5%*	*Overall accuracy*			*81.3%*

Landscape Metrics Analysis

Today, cause of the widespread recognition that landscape is a dynamic entity, one of greatest challenge confronting landscape pattern analysis is quantifying temporal variations in landscape pattern metrics [Cushman and McGarigal, 2008]. Landscape metrics (also referred as landscape indices or as spatial metrics) are one of the key factors of modern landscape ecological research [Uuemaa et al., 2009] and in landscape planning. The landscape or spatial metrics, which have been used to quantify spatial patterning of 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 categorised in different patch classes. In particular, spatial metrics have the capability to describe composition and spatial arrangement of the LC types in a landscape. Therefore, they can be used to describe landscape patterns and structures. When applying spatial metrics, the spatial unit used is called patch, defined as a relatively homogeneous area that differs from its surroundings [Forman, 1995]. A major value of landscape metrics lies in their usefulness for comparing alternative landscape configurations, for example in evaluating the same landscape at different time periods [Gustafson, 1998]. The approach pursued combines RS and landscape metrics to understand spatial-temporal patterns of LC, like urban-rural gradient analysis [Luck and Wu, 2002; Ji et al, 2006].

Starting from the above described information about LC and its changes, three fundamental dates have been chosen to perform landscape metrics analysis: 1954, 1985 and 2004. Logically, 1954 and 2004 have been chosen because are placed at the start and at the end of the overall period of analysis, while the intermediate step has been fixed at 1985 because this date is more significant for the LC changes happened within the area (few years after the 1980 earthquake), rather than a mere choice of the mid-term year.

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 (Fig. 3): each transect is formed by one row and subdivided into eleven 2 km x 2 km blocks. The spatio-temporal dynamics of the landscape mosaic of the study area have been detected by means of a set of landscape metrics, chosen and calculated for the two defined transects [Fichera et al. 2010].

Table 5 - Total LC changes for the types defined: dynamics from 1954 to 1975 (A), from 1975 to 1985 (B), from 1985 to 1993 (C) and from 1993 to 2004 (D). Area values are expressed in [ha].

A - Dynamics 1954÷1975	Urban	Grassland pasture	Cropland	Woodland	**1954**
Urban	893,45	0,00	0,00	0,00	**893,45**
Grassland/pasture	28,77	561,88	837,25	159,61	**1587,51**
Cropland	342,21	42,06	29347,26	1238,67	**30970,19**
Woodland	29,11	23,09	1002,13	21399,38	**22453,71**
1975	**1293,53**	**627,03**	**31186,64**	**22797,67**	**55904,86**

B - Dynamics 1975÷1985	Urban	Grassland pasture	Cropland	Woodland	**1975**
Urban	1256,84	0,00	0,00	0,00	**1256,84**
Grassland/pasture	30,06	425,13	137,54	34,48	**627,22**
Cropland	1482,36	649,65	28516,42	573,14	**31221,57**
Woodland	45,05	162,97	435,72	22155,50	**22799,23**
1985	**2814,31**	**1237,76**	**29089,67**	**22763,12**	**55904,86**

C - Dynamics 1985÷1993	Urban	Grassland pasture	Cropland	Woodland	**1985**
Urban	2754,19	0,00	0,00	0,00	**2754,19**
Grassland/pasture	30,35	433,72	622,02	181,78	**1267,87**
Cropland	584,30	3,71	27327,98	1193,36	**29109,35**
Woodland	21,56	9,61	569,83	22172,45	**22773,45**
1993	**3390,42**	**447,04**	**28519,82**	**23547,58**	**55904,86**

D - Dynamics 1993÷2004	Urban	Grassland pasture	Cropland	Woodland	**1993**
Urban	893,45	0,00	0,00	0,00	**893,45**
Grassland/pasture	103,83	347,23	738,76	397,69	**1587,51**
Cropland	3933,91	994,97	19017,35	7023,96	**30970,19**
Woodland	173,26	663,59	2179,54	19437,33	**22453,71**
2004	**5104,44**	**2005,79**	**21935,66**	**26858,98**	**55904,86**

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 at class level. The results of metric analysis are dependent upon the input spatial resolution; in this study, the pixel size of 30 m has been chosen.
After Cushman et al. [2008], the following landscape metrics have been selected: Contagion (CONTAG); LPI (Largest Patch Index) index for large patch dominance

component; Patch Density (PD), NP (Number of Patches) for subdivision and spatial configuration of the landscape

NP is a simple measure of the extent of subdivision or fragmentation of the patch type. In particular, NP illustrates the diffuse sprawling development and the fragmentation of rural areas. NP is simply the total number of patches and is a measure of landscape configuration and is closely related to spatial scale of analysis and to the extent of the landscape. Therefore, this metric is more meaningful for comparing the same landscape or landscape with similar size and characteristics. NP and PD reveal the landscape fragmentation process [Botequilha Leitão et al., 2006] and they serve as good fragmentation and heterogeneity indices when used to compare the same landscape in different time periods. On the other hand, PD facilitates comparisons among the sub-plots defined in terms of fragmentation caused by urbanization process.

The Largest Patch Index (LPI) indicates the percentage of class accounted for by largest patch and is a simple measure of the dominance of a LC type.

Contagion (CONTAG) measures the degree to which patch types (class) are distributed in a clumpy manner instead to being dispersed in many smaller fragments. In other words, this metric is a measure of landscape configuration and texture and refers to the tendency of classes to be spatially aggregated. CONTAG provides an objective means for quantifying the spatial pattern differences between landscapes [Botequilha Leitão et al., 2006]. Therefore, this index is meaningful in order to compare spatial and temporal dynamics in the same landscape in different times. CONTAG approaches 0 when the patch types are maximally disaggregated, 100 when they are maximally aggregated [McGarigal and Marks, 1995; Botequilha Leitão et al., 2006].

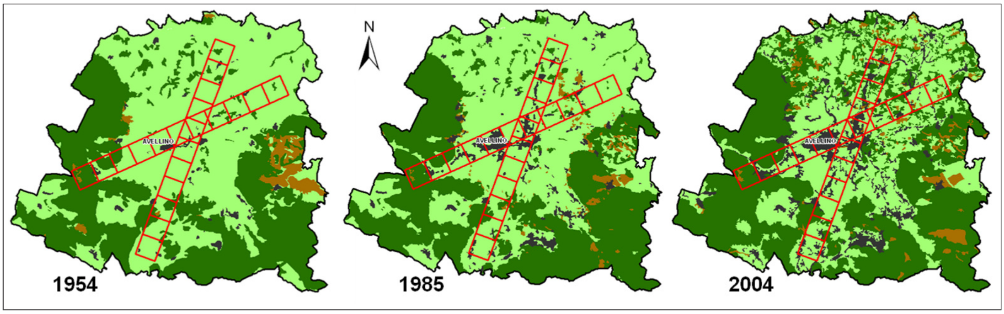


Figure 3 - Location of the two transects (eleven 2 km x 2 km blocks per each transect) across the study area.

Results and discussion

The results coming from the study here described, indicates that the urbanization has considerably modified the LC of the study area, with significant land conversions. Urbanization is a complex diffusion process that is spreading dramatically and which affecting rural landscape differently in space and at different scales [Antrop, 2000;Yeh and Huang, 2007].

Figure 5 depicts changes and dynamics of LC happened during the overall period (1954÷2004), while the unchanged areas are blank filled.

In particular, during the five decades analysed, the Urban LC type has almost quintupled passing from 893.45 hectares to 5,104.44 (from the 1.6% to the 9.1% of the total area of study), mostly at the expense of the cultivated areas, which have most suffered the effects of the expansion of the built-up areas. Woodland and Grassland/Pasture LC types have, instead, shown a relatively lower change rate, although the first one category has recorded a valuable 16% increment between 1954 and 2004 (Table 5).

This paper presents results concerning four landscape metrics for the two subplots transects defined: NP, LPI, CONTAG and PD. For each transect and for each of the three periods focused (1954, 1985 and 2004), the trends of these metrics are shown in Figure 4.

During the period examined, all of stages of land transformations [*sensu* Forman, 1995; Botequilla Leitão et al., 2006] are occurred. In the first time period (1954÷1985) perforation process was dominant except in some subplots in SW-NE transect (Figg. 3 and 4). Dissection process was dominant in the second period (1985÷2004) mostly due to highway A16 construction as well as *fragmentation* process; these two processes characterizing both transects in particular in some subplots where the new infrastructures are initiators and attractors for new urbanization [Antrop, 2000]. Furthermore, this second period was characterised by significantly suburban spreading of some residential and industrial areas connected to reconstruction after the earthquake. This phenomenon are leading to *attrition* process (gradual loss of remaining fragments) indicated as the third and final stage of land transformations.

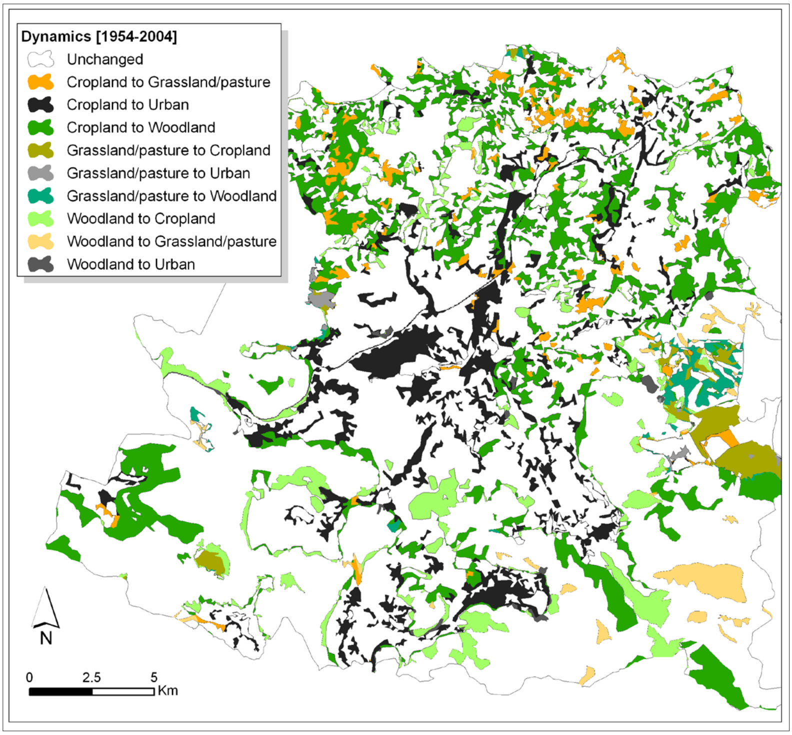


Figure 4 – LC changes and dynamics within the study area for the overall time span 1954÷2004.

Cropland, the largest class at the beginning of the study period, was mainly distributed in the lowland area in the centre of the Conca di Avellino (Fig. 2) and has changed the most because of human activities. It is also possible to partially retrieve such decrease of Cropland LC type into the census data achieved from the ISTAT (Italian National Institute of Statistics, www.istat.it) in relation to agriculture activities. The last two surveys available (ISTAT General Agriculture Census 1990 and 2000) have recorded a decrease of permanent farming and arable areas, with rates of 13% and 55% respectively, and are very useful to statistically explain and support the LC change detected by means the above described approach. Urbanized areas represent the LC type with the largest growth: the maximum increase occurred in the second period from 1985 to 2004 and coincides with the reconstruction process started after the 1980 quake.

The variations among LC patterns can be explained by the proximity of Avellino to other urban centres (Atripalda, Mercogliano and Monteforte Irpino, all of which have over 10,000 inhabitants). All those towns are currently in a territorial continuity with the main settlement of Avellino and this interaction give rise to the urban sprawl phenomenon which, during the last years, has interested the area.

The transformation of urbanized areas is generally related to population dynamics [Bhatta, 2009], that drives the built-up area to expand. Verburg et al. [2001] related the physical growth of a city directly to its population growth, as an increase in population size that encouraged the agglomeration of businesses and new urban development. Moreover, the presence and accessibility of transportation routes force patterns of urban growth. Nevertheless, it is important to outline the peculiarity of the case study zone, where the 1980 earthquake has represented a key factor in land transformation. In fact, quite a lot of buildings in the settlements within the study area became uninhabitable after the seismic event. Therefore, the fear of new tremors, jointly with the wish to leave the most damaged zones, encouraged many people in choosing new localizations to build. The consequence was an outward expansion of urban areas.

To identify the sprawl within the study area, a careful comparison of urbanized area expansion and population dynamic has been carried out. Thus, changes in LC have been compared whit the demographic data achieved from the ISTAT: while the total population within the study area increased by 14% between 1971 and 2001, urbanized areas increased by 75% between 1975 and 2004 (85% between 1954 and 2004). The comparison clearly indicates that growth rate of urbanized areas is always higher than the growth rate of population, during all the time span considered.

Focusing to the area surrounding Avellino, the inhabitants were 36,965 in 1951, 41,825 in 1961, 52,382 in 1971, 56,862 in 1981 (source: ISTAT). On the other hand, between 1981 and 2001 it is possible to observe the beginning of a decreasing trend (55,662 in 1991 and 52,703 in 2001), 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 90,000 inhabitants. This remark is corroborate considering the census data from 1951 to 2001: Mercogliano and Monteforte Irpino have demonstrate high growth rates of population (+72% and +53%, respectively), instead of the above mentioned situation of Avellino (Fig. 6). This urban sprawl is also a direct consequence of the presence of A16 Highway ("Autostrada dei due mari", that have two exits within the area: "Avellino West" and "Avellino East") and S.S. 7bis ("Terra di Lavoro"), that connects in sequence Monteforte Irpino, Mercogliano, Avellino and

Atripalda. The analyses conducted along the W-E transects (Figg. 3 and 5) have allowed to detect significant gradient of landscape patterns just in this direction, as a direct result of the course of these important road axis [Yu and Ng, 2007].

The growth rate of urbanized areas is also due to ineffectiveness of Master Plans, which haven't allowed a reduction in house costs and encouraged people to build in countryside where is often cheaper. Another aspect is related to the low quality of neighbourhoods built in last decades (i.e. lack of parking and green spaces), that has brought citizens to live in countryside.

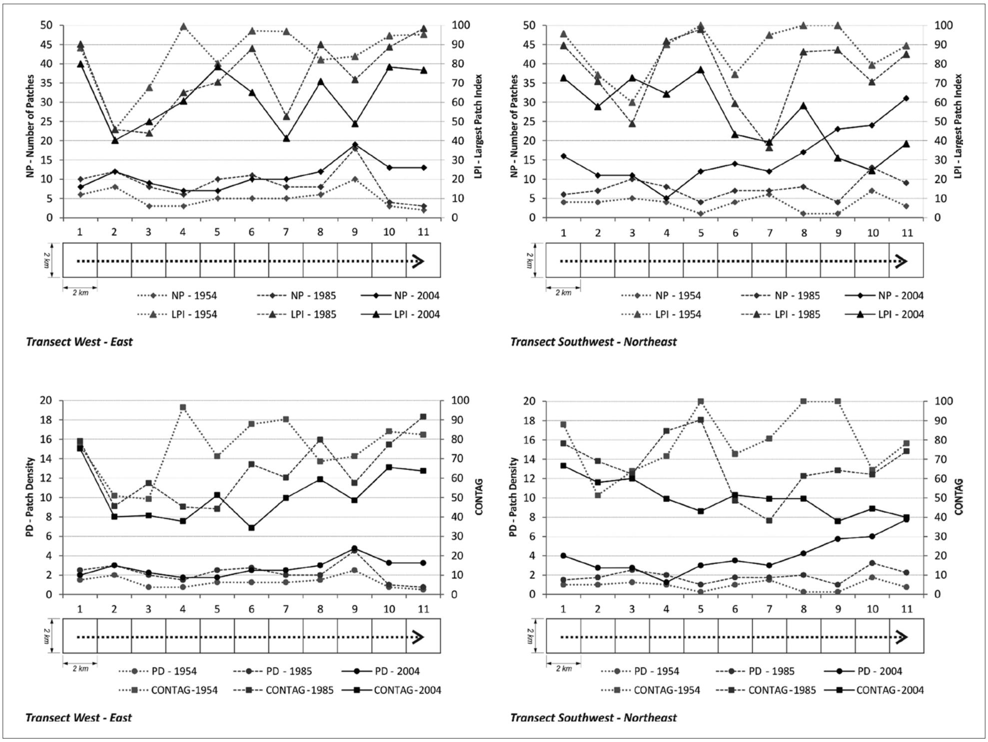
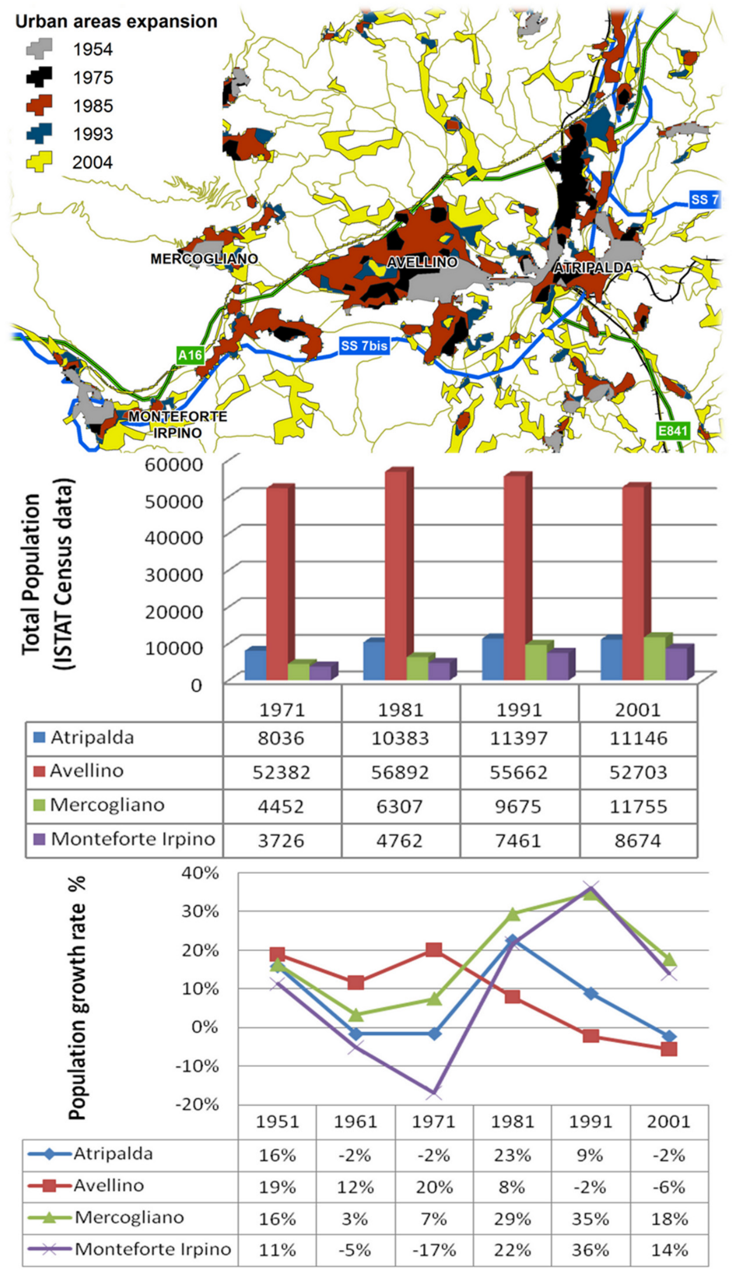


Figure 5 - Spatio-temporal changes in the blocks along the W-E and the SW-NE transect for NP, LPI, SHDI and PD metrics in the three different time periods investigated (1954, 198, 2004).

Almeida et al., [2005] connected urban growth also to economic growth, assuming that there is a relationship between people's economic status, available areas to be built up and expansion of urbanized area. It isn't easy to establish such relationship, because numerous economic parameters should be considered: for instance, per capita income, which however presents the disadvantage to average the data. To overtake this problem, it is possible to relate the built-up area with the number of working persons only, for the specific reason that they are mainly responsible for new construction. Referring to the study area, the total amount of workers have been extracted from the last four census data available (ISTAT, Industry and services census 1971, 1981, 1991 and 2001): these data show that the urbanized areas have grown at a similar rate as working persons and this factor is probably connected to the special laws promulgate after the 1980 earthquake (Law n. 219/1981 and later). These laws were the general framework of P.I.C.A. and P.U.C. plans, from whose has come the indication to place the areas devoted to the industrial use in the northern zone of Avellino.



	1971	1981	1991	2001
Atripalda	8036	10383	11397	11146
Avellino	52382	56892	55662	52703
Mercogliano	4452	6307	9675	11755
Monteforte Irpino	3726	4762	7461	8674

	1951	1961	1971	1981	1991	2001
Atripalda	16%	-2%	-2%	23%	9%	-2%
Avellino	19%	12%	20%	8%	-2%	-6%
Mercogliano	16%	3%	7%	29%	35%	18%
Monteforte Irpino	11%	-5%	-17%	22%	36%	14%

Figure 6 - Urban expansion evolution (1954÷2004) and population census data about Avellino municipality and the major neighbour towns.

This factor has represented another important push to the urban expansion along the SW-NE direction, whose modifications and transformations (Fig. 4) have been well interpreted by the landscape metrics analysis conducted along the SW-NE transect (Figg. 3 and 5), that includes the new industrial estate of Avellino.

Acknowledgements

The authors wish to thank, in particular, one of the two anonymous reviewers for his valuable comments on the earlier draft of this paper.

References

Almeida C.M., Monteiro A.M.V., Mara G., Soares-Filho B.S., Cerquera G.C. Pennachin C.S.L., Batty M. (2005) - *GIS and remote sensing as tools for the simulation of urban land-use change.* International Journal of Remote Sensing, 26: 759-774. http://dx.doi.org/10.1080/01431160512331316865.

Angel S., Sheppard S.C., Civco D.L. (2005) - Th*e Dynamics of Global Urban Expansion.* (Washington, DC: Transport and Urban Development Department, the World Bank).

Antrop M. (2000) - *Changing patterns in the urbanized countryside of Western Europe*. Landscape Ecology, 15 (3): 257-270. http://dx.doi.org/10.1023/A:1008151109252.

Antrop M. (2004) - *Landscape change and the urbanization process in Europe.* Landscape and Urban Planning, 67: 9-26. http://dx.doi.org/10.1016/S0169-2046(03)00026-4.

Bhatta B. (2009) - *Analysis of urban growth pattern using remote sensing and GIS: a case study of Kolkata, India*. International Journal of Remote Sensing, 30: (18): 4733-4746. http://dx.doi.org/10.1080/01431160802651967.

Bolstad P.V., Lillesand T.D. (1991) - Rapid *Maximum Likelihood classification*. Photogrammetric Engineering & Remote Sensing, 57: 67-74.

Botequilha Leitão A., Miller J., Ahern J., McGarigal K. (2006) - *Measuring Landscapes: A Planner's Handbook*. Island Press, Washington DC.

Congalton R.G. (1991) - *A review of assessing the accuracy of classifications of remotely sensed data*. Remote Sensing of Environment 37 (1): 35-46. http://dx.doi.org/10.1016/0034-4257(91)90048-B.

Congalton R.G., Green K. (2009) - *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices.* CRC Press Taylor & Francis Group, Boca Raton, FL.

Congalton R.G., Macleod R.D. (1994) - *Change detection accuracy assessment on the NOAA Chesapeake Bay Pilot Study*. Proceedings of the International Symposium on the Spatial Accuracy of Natural Resources Data Bases, ASPRS, Williamsburg, Virginia, 16-20 May, pp. 78-87.

Cushman S.A., McGarigal K. (2008) - *Landscape Metrics, Scales of Resolution*. In K. von Gadow and Pukkala T., *Designing Green Landscapes*, Springer B.V., pp. 33-51.

Cushman S.A., McGarigal K., Neel M.C. (2008) - Parsimony *in landscape metrics: Strength, universality, and consistency.* Ecological Indicators 8: 691-703. http://dx.doi.org/10.1016/j.ecolind.2007.12.002.

Dewan A.M., Yamaguchi Y. (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. http://dx.doi.org/10.1007/s10661-008-0226-5.

Dimyati M., Mizuno K., Kobayashi S., Kitamura T. (1996) - *An analysis of land use/*

cover change using the combination of MSS Landsat and land use map-a case study in Yogyakarta, Indonesia. International Journal of Remote Sensing, 17: 931–944. http://dx.doi.org/10.1080/01431169608949056.

EEA (European Environment Agency) (2006) - *Urban sprawl in Europe: The ignored challenge*. EEA Report No. 10/2006, Copenhagen, Denmark.

Fichera C.R., Modica G., Pollino M. (2010) - *Remote sensing and GIS for rural/urban gradient detection.* Proceedings of the XVIIth World Congress of the International Commission of Agricultural Engineering (CIGR), Québec City, Canada.

Fichera C.R., Modica G., Pollino, M. (2011) - *GIS and Remote Sensing to Study Urban-Rural Transformation During a Fifty-Year Period*. Computational Science and Its Applications-ICCSA 2011, Springer, pp. 237–252. doi: 10.1007/978-3-642-21928-3_17.

Forman R.T.T. (1995) - *Land Mosaics: The Ecology of Landscapes and Regions.* Cambridge University Press, Cambridge, UK.

Gomarasca M. (2009) - *Basics of Geomatics*. Springer Dordrecht Heidelberg, London New York, p. 656. doi: 10.1007/978-1-4020-9014-1.

Gustafson E.J. (1998) - *Quantifying landscape spatial pattern: What is the state of the art.* Ecosystems, pp. 143-156. doi: 10.1007/s100219900011.

Herold M.,.Goldstein N.C, Clarke K.C. (2003) - *The spatiotemporal form of urban growth: measurement, analysis and modeling*. Remote Sensing of Environment, 86: 286-302. http://dx.doi.org/10.1016/S0034-4257(03)00075-0.

Huang B., Zhang L., Wu B. (2009) - *Spatiotemporal analysis of rural–urban land conversion*. International Journal of Geographical Information Science, 23 (3): 379-398. http://dx.doi.org/10.1080/13658810802119685.

Jensen, J.R., Ramsat E.W., Mackey H.E., Christensen E.J., Sharitz R.P. (1987) - *Inland wetland change detection using aircraft MSS data*. Photogrammetric Engineering and Remote Sensing, 53: 521-529.

Jensen J.R. (2000) - *Remote Sensing of the Environment: an Earth Resource Perspective*. Prentice Hall, Saddle River, NJ.

Ji W, Ma J., Twibell R.W., Underhill K. (2006) - *Characterizing urban sprawl using multi-stage remote sensing images and landscape metrics*. Comput Environ Urban 30: 861-879. http://dx.doi.org/10.1016/j.compenvurbsys.2005.09.002.

Lillesand T.M., Kiefer R.W. (1999) - *Remote Sensing and Image Interpretation*. New York: John Wiley and Sons.

Lillesand T., Kiefer R., Chipman J. (2003) - *Remote sensing and image interpretation*. Wiley, New York, Fifth edition, p.784.

Lu D., Mausel P., Brondízio E., Moran E. (2004) - *Change detection techniques*. International Journal of Remote Sensing, 25 (12): 2365-2401. http://dx.doi.org/10.1080/0143116031000139863.

Lucas R., Rowlands A., Brown A., Keyworth S., Bunting P. (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. doi: doi:10.1016/j.isprsjprs.2007.03.003.

Luck M., Wu J. (2002) - *A gradient analysis of urban landscape pattern: A case study from the Phoenix metropolitan region, Arizona, USA*. Landscape Ecology, 17 (4): 327-339. http://dx.doi.org/10.1023/A:1020512723753.

Lunetta R.S., Elvidge C.D. (1998) - *Remote Sensing Change Detection: Environmental Monitoring Methods and Applications*. Taylor and Francis, London.

Masek J.G., Lindsay F.E., Goward S.N. (2000) - *Dynamics of urban growth in the Washington DC metropolitan area, 1973-1996, from Landsat observations.* International Journal of Remote Sensing, 25: 3473-3486. http://dx.doi.org/10.1080/014311600750037507.

McGarigal K., Marks B.J. (1995) - *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure.* Gen. Tech. Rep. PNW-GTR-351. Portland, OR: USDA, Forest Service, Pacific Northwest Research Station.

Schowengerdt R.A. (1997) - *Remote Sensing: Models and Methods for Image Processing*. 2nd ed, Academic Press, San Diego.

McGarigal K., Cushman S.A., Neel M.C., Ene E. (2002) - *FRAGSTATS: spatial pattern analysis program for categorical maps.* Computer software program produced by the authors [http://www.umass.edu/landeco/ research/fragstats/fragstats.html].

Murgante B., Danese M. (2011) - *Urban versus Rural: the decrease of agricultural areas and the development of urban zones analyzed with spatial statistics*. International Journal of Agricultural and Environmental Information Systems, 2 (2): 16-28. http://dx.doi.org/10.4018/jaeis.2011070102.

Petit C.C., Lambin E.F. (2001) - *Integration of multi-source remote sensing data for land cover change detection.* International Journal of Geographical Information Science. 15 (8): 785-803. http://dx.doi.org/10.1080/13658810110074483.

Singh A. (1989) - *Digital Change Detection Techniques using Remotely Sensed Data*. International Journal of Remote Sensing, 10: 989-1003. http://dx.doi.org/10.1080/01431168908903939.

Song C., Woodcock C.E., Seto K., Lenney M.P., Macomber S. (2001) - *Classification and change detection using Landsat TM data: when and how to correct atmospheric effects.* Remote Sensing of Environment 75: 230-244. http://dx.doi.org/10.1016/S0034-4257(00)00169-3.

Sudhira H.S., Ramachandra T.V., Jagdish K.S. (2004) - *Urban sprawl: metrics, dynamics and modelling using GIS.* International Journal of Applied Earth Observation and Geoinformation, 5 (1): 29-39. http://dx.doi.org/10.1016/j.jag.2003.08.002.

Taylor J.C., Brewer T.R., Bird A. C. (2000) - *Monitoring landscape change in the national parks of England and Wales using aerial photo interpretation and GIS*. International Journal of Remote Sensing, 21: 2737–2752. http://dx.doi.org/10.1080/01431160050110269.

Uuemaa E., Antrop M, Roosaare J., Marja R., Mander Ü. (2009) - *Landscape Metrics and Indices: An Overview of Their Use*. In Landscape Research. Living Rev. Land. Res., 3 (1). URL (cited on <27 July 2011>): http://www.livingreviews.org/lrlr-2009-1.

Verburg P.H., Koning G.H.J., Kok K., Veldkamp A., Priess J. (2001) - *The CLUE modelling framework: an integrated model for the analysis of land use change.* In: Singh, R.B., Jefferson, F., Himiyama, Y. (eds). Land Use and Cover Change. Science Publishers, Enfield, N

Ward D., Phinn S.R., Murray A.T. (2000) - *Monitoring growth in rapidly urbanizing areas using remotely sensed data.* Professional Geographer, 52: 371-386. http://dx.doi.org/10.1111/0033-0124.00232.

Wilson E.H., Hurd J.D., Civco D.L., Prisloe S., Arnold C. (2003) - *Development of a geospatial model to quantify, describe and map urban growth.* Remote Sensing of

Environment, 86 (3): 275-285. http://dx.doi.org/10.1016/S0034-4257(03)00074-9.

Yang X., Lo C.P. (2002) - *Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area*. International Journal of Remote Sensing, 23 (9): 1775-1798. http://dx.doi.org/10.1080/01431160110075802.

Yeh C.T., Huang S.L. (2009) - *Investigating spatiotemporal patterns of landscape diversity in response to Urbanization*. Landscape Urban Plan 93: 151-162. http://dx.doi.org/10.1016/j.landurbplan.2009.07.

Yu X.J., Ng C.N. (2007) - *Spatial and temporal dynamics of urban sprawl along two urban–rural transects: A case study of Guangzhou, China*. Landscape Urban Plan 79: 96-109. http://dx.doi.org/10.1016/j.landurbplan.2006.03.008.

Yuan F., Sawaya K.E., Loeffelholz B.C., Bauer M.E. (2005) - Land *cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing.* Remote Sensing of Environment, 98 (2&3): 317-328. http://dx.doi.org/10.1016/j.rse.2005.08.006.

Received 18/02/2011, accepted 27/04/2011