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Use of multi-temporal and multispectral satellite data for urban change detection analysis

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Urban land cover/use types and their areal distributions are fundamental data required for a wide range of studies in the physical and social sciences, as well as by municipalities for land planning purposes. Remote sensing is a key application in global-change science, being very useful for urban climatology and landuse-landcover dynamics analysis. Investigation of radiation properties, energy balance and heat fluxes is based on satellite data from various satellite sensors and in-situ monitoring data, linked to numerical models and quantitative biophysical information extracted from spatially distributed NDVI-data and net radiation. Spectral signatures of different terrain features are used to separate surface units and to classify them into general categories. Have been analysed multi-spectral and multi-temporal digital imagery data (LANDSAT TM, ETM; SAR, MODIS) for Bucharest metropolitan area over 1989 – 2004 period. It provides the most reliable technique of different urban structures monitoring of net radiation and heat fluxes associated with urbanization at the regional scale. The changes over the years of surface biophysical parameters are examined in association with landuse changes to illustrate how these parameters respond to rapid urban expansion. The land cover information provide a spatially-temporally view of urban environment, being an important complement to in-situ measurements.

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1. Introduction

Cities play a vital role in social and economic development in all countries. Urban environmental changes can be investigated on different spatial and temporal scales. The quality of urban environment directly influences the social and economic development of the city. Urban environment planning and management is the major channel to control the human activities that pollute urban environment and perform the managing measures to improve the bad environmental quality.

Environmental urban changes evaluation is one of the evaluation activities to get the information on environmental condition and in support of the policy making and selection during environment planning and management. It can help to identify the major issues, priority area. Effective planning is based on the completely and precisely understanding of the trends of the environmental parameters in urban area.Urban environment consists of two components: 1) the natural environment, which includes the total of varieties of different natural phenomena and elements, such as terrain, geology, air, water, soil, and climate (original environment); 2) the artificial environment, including urban social environment and urban environment pollution resulted from human's activities. The social environment represents urban socio-economic and cultural conditions. Urban land cover types and their areal distributions are fundamental data required for a wide range of studies in the physical and social sciences, as well as by municipalities for land planning purposes.

Urban zone represents a highly complex area containing a continuum variety of many different spatial, temporal and spectral scales: spatial variability due to the varied landscape; temporal variations are attributed to periodic seasonal changes over the year; spectral variability is due to the great variety of materials and structured associated with the urban area.

Land covers, as the biophysical state of the earth's surface and immediate subsurface, are sources and sinks for most of the material and energy movements and interactions between the geosphere and biosphere. Changes in urban land cover include changes in biotic diversity, actual and potential primary productivity, soil quality, runoff, and sedimentation rates, and cannot be well understood without the knowledge of land use change that drives them. Therefore, urban land use and land cover changes have environmental implications at local and regional levels, and perhaps are linked to the global environmental process. Urbanization, the conversion of other types of land to uses associated with growth of populations and economy, is a main type of land use and land cover change in human history. It has a great impact on climate. By covering with buildings, roads and other impervious surfaces, urban areas generally have a higher solar radiation absorption, and a greater thermal capacity and conductivity, so that heat is stored during the day and released by night. Therefore, urban areas tend to experience a relatively higher temperature compared with the surrounding rural areas [1]. In Romania, land use and land cover patterns have undergone a fundamental change due to accelerated economic development under its economic reform policies since 1989. Urban growth has been speeded up, and extreme stress to the environment has occurred. This is particularly true for Bucharest metropolitan areand surrounding regions. In the last 15 years, construction activities have been explosively developed in Bucharest area, with minimum geotechnical assistance.

2. Applications of remote sensing digital imagery to urban changes

Satellite remote sensing is used as an important technology to help urban research to support research analysis of spatial dynamics and urban morphology. A difficulty in using remote sensing technology for urban studies is the diversity of features found in the urban environment, including different targets like concrete, asphalt streets and avenues, roofs of different materials, exposed soil, grass, trees, and water .Some of these targets are smaller than the pixel resolution. A landscape is composed of ever-changing elements. Their spatial and temporal patterns distinguish a landscape to an observer; at the same time they inform us of the complexity of dynamic processes at various scales. The changing pattern of the landscape, including the changing biophysical properties of that landscape, is a central theme in the fields of landscape ecology and environmental quality management and planning. The research and management issues are focused upon the relationship between the changes that occur in the composition of the landscape and the spatial configuration of landscape elements. The essential goal of modeling and monitoring urban change from remotely sensed data is to compare images at a spatial and temporal resolution appropriate to the ecological scale of the processes of interest. Satellite remote sensing instruments provide measurements at a variety of pixel resolutions, spatial extents and temporal scales. However, due to variability in illumination, atmospheric effects, and instrument calibration, conventional supervised or unsupervised classification techniques have difficulty providing pixel to pixel comparisons between images from different times. Classification of any given pixel into a discrete land cover class for the purpose of determining change requires that these variables be considered. Different mathematical approaches were applied to modeling land use dynamics. Change detection is the process of identifying differences in the state by observing it at different times.Various change detection techniques have been developed for analyzing of spatio-temporal modifications in natural and anthropogenic surface features [2].

Digital change detection comprises the quantification of temporal phenomena from multi-date imagery. The natural evolution of the urban surface (due to the difference in acquisition dates) must be taken into account and separated from any abnormal evolution, herein generally termed as ‘‘change’’.

Remote sensing platforms are becoming more numerous, and have improved spatial and spectral resolutions, bringing closer the goal of surface operational monitoring. The problem involves detecting changes between two data sets: one before and the other after the change. In the case of progressive or gradual changes, such as erosion, reforestation, urban infrastructure changes, more than one image may be necessary [3].

Two of the most common uses of multispectral and multitemporal satellite images are mapping landcover via image classification and landcover change via change detection and derived surface bio-geophysical parameters. The recent launch of several new satellites, which have sensors on board that include channels specifically designed for the observation of urban features (air, soil, vegetation, water) are expected to greatly increase our understanding of the urban system changes and functioning. The large amount and good quality of available data also gives spurs to improve on existing algorithms or develop new algorithms. Compared to observations over the oceans, where the surface reflectance is very homogeneous and low in the infrared, most land surfaces have a complex spectrally and spatially dependent reflectivity, which makes it difficult to decouple the atmospheric from the surface signal. Remote sensed imagery is used frequently by urban planners in synergy with other demographic or geographic information to provide a more detailed and insightful picture of the human landscape. Cities reflect economic, environmental, technological, and social processes in their change, yet all are in turn profoundly driven by the evolving urban spatial structure itself. Research has explored using remote sensing in concert with other sources of data in modeling urban land use change. These investigations exploit the fact that remote sensing can provide synoptic views with high detail and high temporal frequency. Remote sensing products can be used to map major urban features, land cover types, detailed land use or urban infrastructure, from which can be derived secondary socioeconomic parameters and the invisible elements of urban infrastructure. Remote sensing also contributes to a better representation of the spatial heterogeneity of cities, a counter tendency to the limitations of models that tend to reduce geographic space to the single dimension of distance, thereby hiding important spatial patterns in land use and landscape features. The combination of remote sensing with urban modeling has been mentioned as a priority for future exploration and evaluation. Furthermore, empirical studies have substantiated the use of both spatial metrics and remote sensing in urban modeling.

2. Study area and data used

2.1. Test area

Study area, urban zone Bucharest, Romania, bounded by latitudes 44.33 °N and 44.66 °N and longitudes 25.90 °E and 26.20 °E was selected along a climatic and environmental gradient and was characterized in terms of hydrology, geomorphology, soil and vegetation properties, that control or contribute to functioning. Central part of Bucharest city has the main coordinates: latitude 44°25’ 50’’ and longitude 26° 6’ 50’’. The study area is placed in the Southern part of Romania as is presented by Fig. 1. Bucharest has a star-shaped urban structure, as a result of the particular way of the city’s development over more than 5 centuries (documented since 1459). The city has expanded in a concentric manner around a medieval centre (princier house – named Curtea Veche) as well as a radial one along the roads to the capital of Valachia, later all over Romania, in modern city of Bucharest (approximately 2 millions habitants and 230 km^2). The Dambovita river, a tributary of the Danube, crosses the Northern part of the city, and has meanders, partly filled by an artificial lake. Other lakes are visible in the center and in the lower part of the image. The circular zone in the South is a forested area, with a large building in the center. The city has a total surface of 226 km^2. The altitude varies between 55.8 meters at the Dâmbovita bridge in Cãtelu, south-eastern Bucharest, to 91.5 m at the Militari church. Several lakes stretch across it, the most important being Lake Floreasca, Lake Tei and Lake Colentina. In the center of the capital there is also a small artificial lake Ciurel.

Fig. 1. Test site positioning of Bucharest area.

2.2. Data used

The investigations were focused on estimating of urban environmental parameters from satellite multispectral data based on satellite images from Landsat TM, ETM, SPOT, SAR.

Was used Landsat TM data acquired: 3/07/1984, 27/03/1989, 21/08/1990; Landsat ETM: 23/07/2002, 12/09/2004; and SAR ERS-1 sets of data acquired: 30/07/1992, 25/11/1992, 30/12/1992; and 30/04/1993; 09/06/1993 and 13/08/1993, in PRI (Precision Image) format. All SAR images have been taken in descending mode. Radial direction is almost East-West. In PRI format the speckle is slightly decreased by a multilook processing. The pixel size is 12.5 meter in both directions. The images were geometrically corrected to fit a topographic map with a scale of 1:100 000, on which vectors were digitized for the subsequent geocoding of the satellite images. In situ-monitoring additional data were used. ENVI 4.1, IDL and ILWIS 3.1 softwares were used.

3. Methodology

3.1. Data processing

The main objectives of this investigation were: to develop and validate new techniques for mapping and monitoring urban changes within and around Bucharest area based on satellite sensor images (both optical and microwave) and new digital framework data; to analyze the spatial and temporal pattern of urban system dynamics and air pollutants effects on urban land cover and hence to quantify the degree of changes. Linear and non-linear combinations of channels, Principal Component Analysis (PCA) and Relative Channel Analysis, HIS (Intensity-Hue-Saturation) transforms, spectral mixture analysis and unsupervised classification using Maximum Likelihood algorithm assisted by an unsupervised clustering procedure were applied on the available Landsat TM, ETM, Spot and SAR ERS-1 images for urban area Bucharest, Romania. Ground reference data were acquired to characterize the spectral properties of pure urban surfaces for validation of the image classification. The urban environment represents a spatially and spectrally complex assemblage of different land cover types including diverse impervious surfaces, vegetation, water, and bare soil. Specifically this investigation develops tools and tests the hypothesis that a probabilistic statement of the transition of a pixel can suggest the spatial structure of the landscape patch to which that pixel belongs. Simulating the stochastic nature of change is of fundamental importance in ecology. Spatial and temporal dynamics of landscape are of great importance for optical and stochastic models applied to various landscapes and biophysical processes. Images provided by optical sensors contain information about the surface layer of the imaged objects (i.e. color), while microwave images provide information about the geometric and dielectric properties of the surface or volume studied (i.e., roughness).

Methods involved the integration of data recorded by different satellite sensors, optical and microwave, through newly developed algorithms. In-situ monitoring data regarding, soil, water, vegetation, meteorological conditions were correlated with time of the satellite pass over selected area.

Analogously to the possibility to emphasize spatial and linear structures by filtering in the spatial domain, spectral characteristics of multispectral data can be enhanced by the adaptation of the adequate filters as linear transformation. By comparing the two processing procedures it can be stated that Principal Component Analysis as well as “Spectral Mean Value” show the same thematic information content concerning environmental features.

In order to implement the land-cover allocation process, is required spectral–temporal signatures for urban target classes. These are derived on the basis of a version of the unsupervised classification based on Landsat TM and ETM data. Because urban development is not generally replaced by agricultural or forest land over time, we reclassified as urban all pixels that were labeled urban in the rasterized 1989 land-cover dataset, but not classified as urban in the 2004 unsupervised classification.

3.2. PCA Transform

In PCA (Principal Component Analysis) in change detection, after images belonging to different dates are transformed into component space, individual component image differences can be used to detect changes.

The changes can be detected at the lower-end and higher-end tails of the principle component (PC) difference-image pixel distribution histogram. PCA was explored to support environmental urban change detection [4].

We performed both standardized and non-standardized PCA transformations. We used a simple strategy for linear transformation of multispectral imagery into principal component space [5]. Given a multispectral set of images (X), with r number of pixels in each band and c number of bands, there were r number of rows and c number of columns that define a contingency table. Each entry, xij, was the pixel value in the ith row and jth band. The first step in this strategy was to standardize this X table by replacing each xij element with:

$$a_{ij} = \frac{x_{ij} - \bar{x}_i}{F_i} \quad (1)$$

where $\bar{x}_i$ is the mean value of ith row and Fi is a standardization function. Selection of a standardization function determined whether the transformation was a “principal component analysis” or a “standardized principal component analysis” transformation [6]. Choosing Fi=1 produced row centering as in simple PCA procedures. However, in standardized principal component analysis, the standardization function was:

$$F_i = \sqrt{\sum_{j=1}^{c} (x_{ij} - \bar{x}_i)^2} \quad (2)$$

which is the square root of the sum of squared deviations about the row mean.In the second step, a matrix of Scxc was computed by multiplying the transpose of A by itself:

$$S_{cxc} = A^t_{cxr} A_{rxc} \quad (3)$$

where Scxc denoted a variation–covariation matrix. Diagonal entries were the c number of variances for each band and off diagonal entries were the covariances for all possible two-band combinations. The type of standardization function (Fi) determined if Scxc would be a covariance or correlation matrix [7]. Next was the computation of the eigenvalues and eigenvectors of the Scxc matrix. Eigenvalues (λj) were calculated by solving the equation

$$\left| S_{cxc} - \lambda_j I \right| = 0 \quad (4)$$

where I is the identity matrix. For a cxc matrix like S, there are c eigenvalues. Also associated with each eigenvalue is an eigenvector, which is a non-zero vector uj with the condition Scxcuj=λjuj. This condition could be rewritten as:

$$\left| S_{cxc} - \lambda_j I_{cxc} \right| u_j = 0 \quad (5)$$

By solving the system of linear equations given by Eq. (5), eigenvectors corresponding to eigenvalues were calculated. Eigenvectors were also normalized such that their inner product or sum of squares was equal to 1. At the final step of the PCA transformation, data (X) was linearly transformed into components space by using eigenvectors. In matrix notation, this was Y=XU, where U was the matrix of eigenvectors.

4. Results

The study area is comprised of urbanized, undisturbed, coastal river Dambovita and agricultural regions. These different types of land uses have distinct spatial edge frequencies or texture that can be used as input into classification algorithms. Urban areas typically have significant texture resulting from buildings and street grids, whereas homogeneous areas such as agricultural fields have little to no texture. Land use information for the study site was obtained as a vector polygon coverage. Twenty-four classes are defined in this coverage and include residential, industrial, commercial, agricultural, and natural (undisturbed) land uses. In situ land use data and different radiometric were analyzed too.Land cover types, present in several different land use categories, can cause interpretive difficulties for users of classified data. For example, a vegetation land cover class based on surficial reflectance properties may correspond to residential, vacant, recreational open space, or agricultural land use types. Land use data can also be useful in reclassifying pixels misclassified due to subpixel mixing and edge effects. For example, pixels with a vegetation classification can be reclassified as agricultural vegetation using land use data. Vegetation abundance (derived from Landsat TM and ETM data) combined with surficial water rights data can provide accurate classification of active and fallow agricultural regions. The results of this study indicated that several key land cover classes were confused due to the spectral similarity of these classes. The number of land cover classes used in the initial study 24 was reduced to 8 major classes to reduce misclassification. A hard classification of the Landsat TM, ETM data was then performed using a maximum likelihood decision rule. Bayesian coefficients (weighting factors that reflect the probability of occurrence for a given class in the scene) used in the maximum likelihood classification were somewhat arbitrarily determined based on qualitative estimation of the area each class occupied within the study region. Methods involved the integration of data recorded by different satellite sensors, optical and microwave, through newly developed algorithms. Images provided by optical sensors contain information about the surface layer of the imaged objects (i.e. color), while microwave images provide information about the geometric and dielectric properties of the surface or volume studied (i.e., roughness). Fig. 2 presents such landcover classification of Bucharest area based on Landsat ETM.

Fig. 2. Landsat ETM 23/07/2002, PCA 3/2/1 analysis.

A SAR image multi-temporal composition of three images (3/07/92, 25/11/92, 30/12/92) is representative for Bucharest urban area, comparative with a Landsat TM (21/08/1990) classification is presented in Fig. 3 and the density of the built-up area can be assessed by the strength of the backscattered signal. In contrast to the optical image, highways, large roads and avenues are presented as dark lines. This is also true for the runways on airports, because of the smooth surface. Bridges and railways on the contrary are imaged mostly very brightly due to the dielectric property of metal. The different colors of the agricultural fields depend on the changes in surface roughness occurred between the acquisition dates. Data acquired in spring and summer is used to identify the crop type, a methodology similar to the one applied with optical data.

Data acquired in the winter season is also of great interest, since it reveals the type of field labor performed which is often typical of the preparation of the fields for certain crop. It allows already very early in the year to assess certain crop types and estimate their surfaces. It is obvious that such data application must be based on good knowledge of the time and type of field preparation. Initially sufficient ground survey needs to be available. Fig. 3 is presenting a Landsat ETM, PCA analysis on channels 3/2/1 of Bucharest area. The analysis and interpretation of the different satellite images shows significant variations in the organization of the urban space among central, median and peripheral zones. There are two types of structures in the central and median zones that are in a continue change. The central zone, with its far more complex functions (politico-administrative, cultural, entertainment, residence, etc) displays monumental buildings (continually built from the end of 19 century till these days). The median zone is mostly a residential zone with private houses of a traditional fashion, modestly equipped. The peripheral zone consists of residential neighborhood, with characteristic tall buildings of 4-10 floors, poorly equipped as well as industrial buildings and amusement parks and lakes. It was delimited residential zones of industrial zones which are very often a source of pollution.

Are also emphasized the particularities of the functional zones from different points of view: architectural, streets and urban surface traffic, some components of urban infrastructure as well as habitat quality. The growth of Bucharest urban area in Romania has been a result of a rapid process of industrialization, and also of the increase of urban population.

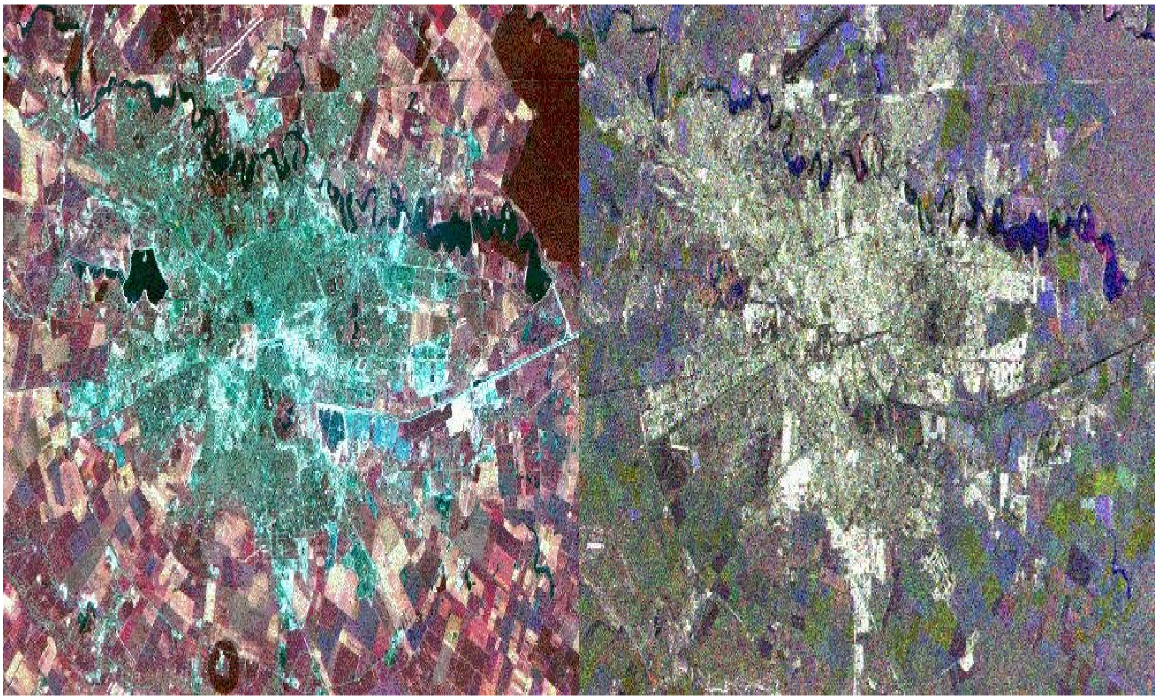

Fig. 3. SAR multitemporal composition of three images (3/07/92, 25/11/92, 30/12/92) (left side) and a Landsat TM (21/08/1990) (right side) for Bucharest.

In the Landsat TM 1984 and Landsat ETM 2004 images, bands 1, 2, 3, 5, and 7 were highly correlated to each other. Band 4 had the lowest correlation to any other band. Band 5 had high co-variance values with other bands in both 1984 and 2004 images. Thus, band 5 had the highest loadings on the PC1 images of both dates after non-standardized PCA transformation. Conversely, band 4 had low co-variances with other bands in the original images. Thus, band 4 in both images had low loadings on PC1 images in the non-standardized PCA transformation. PC1 accounted for information common to all bands. Usually, PC1 is referred to as an intensity component. The contributions of the multispectral bands to PC1 were determined by their covariances with other bands. For example, band 5 had the highest variance and was highly correlated with the other bands (except band 4). Because of its high variance, band 5 had high covariance values with other bands as well. Thus, the contribution of band 5 to the PC1 was the highest on both images. PC2s had the highest loadings from infrared bands. This appeared to be the differences between visible and infrared bands in both images.

Image differencing was applied to PCA transformed images. Brightness values of no-change areas were distributed around the mean value of each difference image. Very dark or bright pixels represented the areas that had been changed between 1989 and 2004 (as can be seen in Figure 4).The comparison of the two Landsat images, TM from 3/07/1984 and ETM from 12/09/2004 highlights how the city grew around its centre. Change area due to the decrease of vegetation was of 12%, while the change area due to increase of buildings was of 14,3%. The overall accuracy was 81%.

Bucharest expanded in all directions during the 20 years covered by the images, and all of its six administrative sectors experienced a considerable growth. Among these, Baneasa, the northern district of the city, was the one which grew the most, almost reaching the lake which bears the same name. Until recently, the regions surrounding Bucharest were largely rural, but after 1989, new suburbs started to be built, in an area well renowned for its natural beauty and the fertility of its land. The region where Bucharest lies was in fact once covered by the Vlasiei forest, which, after it was cleared, gave way to a fertile flatland. Remote sensing is a key application in global-change science, being very useful for urban climatology and landuse-landcover dynamics analysis. Multi-spectral and multi-temporal satellite imagery provide the most reliable technique of monitoring of different urban structures regarding the net radiation and heat fluxes associated with urbanization at the regional scale. Investigation of radiation properties, energy balance and heat fluxes is based on satellite data from various satellite sensors and in-situ monitoring data, linked to numerical models and quantitative biophysical information extracted from spatially distributed NDVI-data and net radiation. For detailed landuse classifications in a digital form is possible to analyze in a statistical way these properties.

This study attempts to provide environmental awareness to urban planners in future urban development. The land cover information, properly classified, can provide a spatially and temporally explicit view of societal and environmental attributes and can be an important complement to in-situ measurements.

Fig. 4. Bucharest urban growth during 1984-2004 based on Landsat TM data.

5. Conclusion

Remote sensing is very useful for urban landcover/use changes assessment, especially in the context of rapid increasing of urbanization in Bucharest, Romania.

Since LANDSAT, SPOT and SAR images contain complementary information, environmental quality and changes of urban areas mapping is more efficient when the images are used in synergy. VIR images contain information about the reflectivity of objects while SAR images contain data about the geometric and electrical characteristics of the objects, radar pulses can also penetrate vegetation to some degree depending on the wavelength and vegetation thickness. The combination of quasi-simultaneously acquired multi-sensor data are used for a better classification. The comparison of the two Landsat images, TM from 3/07/1984 and ETM from 12/09/2004 highlights how the city grew around its centre. Change area due to the decrease of vegetation was of 12%, while the change area due to increase of buildings was of 14,3%. The overall accuracy was 81%.

Satellite data analysis shows a clear contrast between the central, median and peripheral zones of Bucharest city. Information on the spatial pattern and temporal dynamics of land cover and land use of urban areas, is critical to address a wide range of practical problems relating to urban regeneration, urban sustainability and rational planning policy. A pressing requirement is to assess the extent to which predicted demands for new housing can be met through use of urban `brown field' sites. Similar data are also central to the quest for more sustainable urban transport policies. Future researches based on very high spatial resolution images provided by Ikonos and IRS can be useful to produce urban large-scale maps for land management urban planning, geo-marketing, evaluation of urban risk and disasters.

References

[1] Q. Weng, A remote sensing–GIS evaluation of urban expansion and its impact on surface temperature in the Zhujiang Delta, China, Int. Journal of Remote Sensing, **22**(10), 1999–2014 (2001).

[2] M. Batty, D. Howes, D., Predicting temporal patterns in urban development from remote imagery, J. P. Donnay, M. J. Barnsley, & P. A. Longley (Eds.), Remote sensing and urban analysis, 185–204, London: Taylor and Francis (2001).

[3] K. Bergen, D. Brown, J. Rutherforda, E. Gustafson, Change detection with heterogeneous data using ecoregional stratification,statistical summaries and a land allocation algorithm, Remote Sensing of Environment **97**, 434 – 446 (2005).

[4] J. R. Carr, K. Matanawi, K. Correspondence analysis for principal components transformation of multispectral and hyperspectral digital images. Photogrammetric Engineering and Remote Sensing, **65**, 909–914 (1999).

[5] J. A. Ludwig, J. F. Reynolds, Statistical ecology: A primer on methods and computing, 337- 345. New York: John Wiley and Sons, Inc, 1988.

[6] J. F. Morisette, S. Khorram, Accuracy assessment curves for satellitebased change detection. Photogrammetric Engineering and Remote Sensing, **66**, 875–880 (2000).

[7] G. Biging, D. Colby, R. G. Congalton, Sampling systems for change detection accuracy assessment. In R. S. Lunetta, & C. D. Eldvidge (Eds.), MI: Ann Arbor Press, (1998).

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