MASTERS PROGRAM IN

GEOSPATIAL TECHNOLOGIES

SPATIO-TEMPORAL LAND USE/LAND COVER CHANGES ANALYSIS AND MONITORING IN THE VALENCIA MUNICIPALITY, SPAIN

Addis Getnet Yesserie

Dissertation submitted in partial fulfilment of the requirements
for the Degree of *Master of Science in Geospatial Technologies*

Universidade Nova de Lisboa
Universitat Jaume I
Westfälische Wilhelms-Universität Münster

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Dissertation supervised by

Filiberto Pla, PhD

Dept. Lenguajes y Sistemas Informaticos
Universitat Jaume I, Castellón, Spain

Co-supervised by

Marco Painho, PhD
Instituto Superior de Estatística e Gestão da Informação
Universidade Nova de Lisboa, Lisbon, Portugal

Edzer Pebesma, PhD
Institute for Geoinformatics
Westfälische Wilhelms-Universität, Münster, Germany

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Abstract

Issues of land use/land cover changes and the direct or indirect relationships of these changes have drawn much attention in recent years. In the Mediterranean Spain, observed environmental changes influenced with dramatic urban growth and their likely changes can have extensive unforeseen ramification. Thus, the objectives of this research were to map and determine the nature, extent and rate of changes and to analyze the spatio-temporal land use/land cover change patterns and fragmentation that has occurred in Valencia Municipality.

Multi-temporal Landsat MSS1976, TM1992 and ETM2001 images were acquired. Digital orthophotos, IKONOS images and existing Corine land cover maps were used as reference. More than 130 training samples were selected for classification of the Landsat images using supervised method parallelepiped-maximum likelihood algorithm in ERDAS Imagine 9.1, and land cover maps were generated and change detection analysis was performed.

Distinct changes have occurred on the land use/land cover. Built up areas increased from 3415ha (24%) to 4699ha (34%) while agricultural areas decreased from 6560ha (48%) to 5493ha (40%) from 1976-2001. Built up class showed an overall amount and extent of change of 1284ha (39%) while agricultural areas decreased 1067ha (16%) from 1976-2001. The rate of change was as high as 1.8 % for built up surface while agricultural lands were converted at 1% per year. Similarly, the spatial metric calculation e.g., number of patch, largest patch index and patch fractal dimension values revealed a continued growth in the built up surface. Rapid urban growth was contiguous to the historical urban core with less fragmentation. Built up surface expansion followed certain pattern depending on the increasing development pressures, population and highways. Conversely, spatial metrics value for the non-built up classes decreased substantially over time showing prevalence of landscape fragmentations. The change analysis integrated with spatial metrics performed in this research allowed for the monitoring of land use/land cover changes overtime and space. Mapping of the spatio-temporal land use/land cover changes in an accessible GIS platform can be used to supplement the available tools for urban planning and environmental management in the region.

Keywords: Land use/land cover, spatio-temporal, spatial metrics, Mediterranean, Valencia

Acknowledgments

Special thanks to the Almighty God for his guidance and grace that allowed me to stay until this time!

I gratefully acknowledge the EU-Erasmus Mundus Scholarship program for granting me the chance to pursue my studies in the consortium universities. Thanks are also due to coordinators of the program Prof. Dr. Marco Painho, Prof. Dr. Werner Kuhn, Dr. C. Brox and Prof. Dr. Michael Gould.

I express deepest appreciation to my supervisor Prof. Dr. Filiberto Pla, for his guidance, keen advice and suggestion starting from the development of the proposal to the accomplishment of this work. I am grateful to my co-supervisors Prof. Dr. Marco Painho and Prof. Dr. Edzer Pebesma for their suggestion and comments. My sincere gratitude goes to Prof. Dr. Pascual Aguilar from the Center for Research on Desertification in Mediterranean region, Valencia, Spain, who provided me most of the data needed and his unreserved efforts to guide, read and comment on the manuscript of this work. I would have been lost without his efforts and cooperation.

My indebtedness also goes to my professors in the three universities I have attended, Prof. Dr. P. Cabral, Prof. Dr. M. Caetano, Prof. Dr. Angela, Prof. Dr. A. Kruger, Dr. Pedro Latorre, Dr. Hebert, Dr. Lubia Ms. F. Caria and Ms. Dori for their close friendship and academic effort to equip me with basic knowledge and skill within the Geospatial Technologies program. They are role model people for my success in the department and future careers. Moreover, I would like to thank my best friends Mesfin, Yikealo, Yihun, Getnet, Belay, Yibeltal and Saroj and fellow Erasmus Mundus students and friends I meet during my stay in Europe for their close friendship and cooperation and creating international school environment.

I would like to take this opportunity to express my sincere gratitude to my families and friends at home especially my mother W/o Abez Mersha and my brothers, Belachew Getnet and sister Melkam Getnet for taking care of me and their moral support through out the course of my study abroad.

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1. INTRODUCTION

Urban growth is a global phenomena and one of the most important reforming processes affecting both natural and human environment through many ecological and socio-economic processes (Mandelas, et al, 2007). Currently, communities worldwide need spatial data to compensate for and adapt to current urban growth while planning for expected future change and its impacts on infrastructure, as well as the surrounding environment. Rapid rates of urban land use change and rate urbanization are now at the front of local political disputes (Goetz, et al., 2003). However, these polarized debates lack adequate geospatial information for informed decision making and monitoring changes in dramatically changing environments and thereby achieving sustainable urban growth.

In order to understand the evolution of various land use systems, to analyze dramatic changes of land use/land cover at global, continental and local levels, and further to explore the extent of future changes, the current geospatial information on patterns and trends in land use/land cover are already playing an important role. Remotely sensed imageries provide an efficient means of obtaining information on temporal trends and spatial distribution of urban areas needed for understanding, modeling and projecting land changes (Elvidge, at al., 2004).

Meanwhile, one of the most outstanding features in some Mediterranean regions is the intensive (and extensive) process of land use/land cover changes occurred in the last 50 years (Pascual Aguilar, 2002). In particular, over the last ten years, much attention has been drawn to the issues of land use and land cover changes and the direct or indirect relationship these changes might have with the observed environmental degradation in the Mediterranean region (Drake and Vafeidis, 2004). In coastal Mediterranean regions, including Valencia region of Spain, land cover transformations are mainly produced by contemporary socio-economic changes that have produced a drift from traditional agriculture to industrial and tourism economies, reinforced by population’s trends to concentrate in cities or large urban regions (Pascual Aguilar, et. al., 2006). These dynamics place significant strains on the existing land cover and the surrounding available fertile agricultural fields and natural resources. Meanwhile, information on land use and land cover and the way it changes over time is crucial for environmental assessment and for informed decision making. Making this information available in digital map form further increases its value and usefulness for integration with other geographic information and conducting geospatial analysis and monitoring. However, to date, there have been few studies attempting to document the spatial and temporal land use dynamics using remotely sensed imageries and GIS techniques at local scale in the region.

Mapping land use/land cover is now a standard way to monitor changes. Characterizing a landscape and quantifying its structural changes has received a considerable boost from developments in geospatial technologies namely GIS software and multispectral satellite data. Such data became operationally available in the early 1970s and paved the way for land use/land cover studies. Remote sensing provides an efficient tool to monitor and detect land use/land cover changes in and around urban areas since the past three and half decades. They provide high spectral, spatial and temporal resolution data to researchers. With repetitive satellite coverage, the rapid evolution of computer technology and the integration of satellite and spatial data with geographic information system (GIS), development of environmental monitoring applications such as change detection have become ubiquitous (Jensen, 1996; Macleod and Congalton, 1998). To detect land cover change, a comparison of two or more satellite images acquired at different times can be used to evaluate the temporal or spectral reflectance differences that have occurred between them (Yuan and Elvidge, 1998).

In order to monitor urban land use change and development in the region, a change detection analysis was performed to determine the nature, extent and rate of land cover change and fragmentation over time and space. The results quantify the land cover change patterns in the municipality area and demonstrate the potential of multitemporal Landsat data to provide an accurate, economical means to map and analyze changes in land cover in a spatio-temporal framework that can be used as inputs to land type for management and policy decisions with regard to varied themes that has link with space such as urbanization, water management, deforestation, land degradation and so on.

1.1 Objectives

The aim of this study was to analyze and monitor the spatio-temporal land use/land cover change patterns using multitemporal Landsat imageries from the past 25 years (1976-2001) in Valencia Municipality. Besides, it was designed to compare the spatio-temporal urban expansion and land use/land cover fragmentation and conversion rates in temporal and spatial scales.

Specific objectives thus include:

i. to map and determine the nature, extent and rate of spatio-temporal land use/land cover change using multi-temporal Landsat imageries.
ii. to detect and monitor land use/land cover changes using change detection techniques.
iii. to analyze the spatio-temporal land use/land cover change patterns and fragmentation using spatial metrics.

1.2 Research Questions

In order to address the stated objectives, the following research questions were designed.

i. What is the extent and rate of land use/land cover changes that have occurred in the Valencia municipality between 1976, 1992 and 2001?
ii. What is the nature of land use/land cover changes that have taken place in the past periods under study?
iii. What is the spatial and temporal land use/land cover change pattern, fragmentation and structural changes in the land cover units?

The output of this research assumed to fill the research gap through a local scale analysis of landscape structure and change detection using multi temporal imageries in a GIS platform. Results of this research can be utilized as a spatial-temporal land use change map for the region to quantify the extent and nature of development change. It would foster learning about the surrounding environment and planning agencies in developing sound and sustainable land use practices.

1.3 Study Area

The Valencia municipality area is located at in the Valencia Community, South Eastern Spain. It is situated at $39^{0}28'00''$N latitude and $00^{0}22'00''$W longitude (UTM ED_50 datum) geographic coordinates (Figure 1). The municipality lies at the flat coastal Valencia province covering an approximate area of 13795ha.

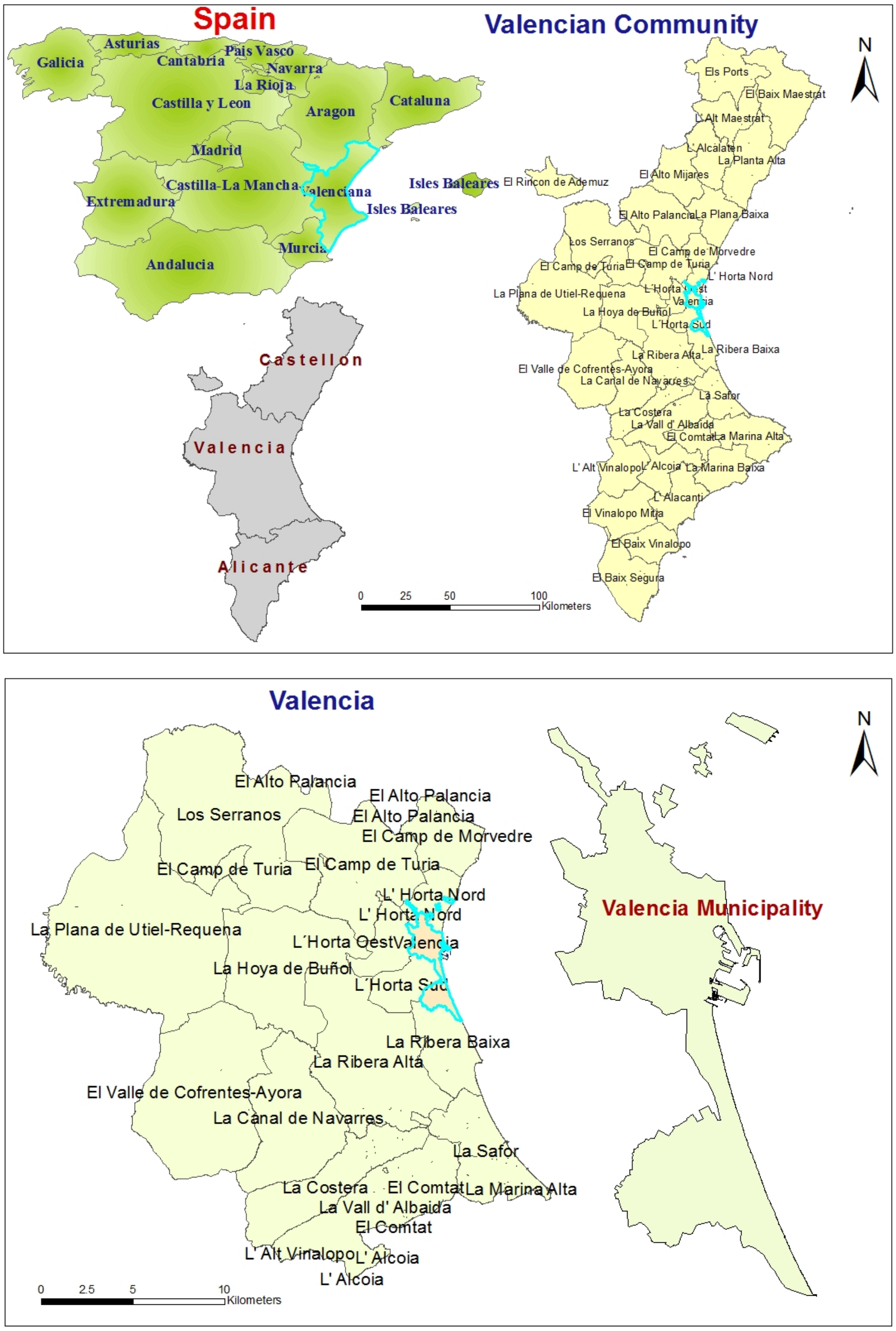

Fig. 1. Map of the study Area

The climate of the region is typically Mediterranean. The municipality of Valencia enjoys a mild temperature Mediterranean climate (Clavero Paricio, 1994). Annual average rainfall is around 550mm mainly distributed in the autumn season, with a minor peak in spring. Annual average temperature (around 17^0C) defines a warm regime. The combination of high temperatures and rainfall scarcity in summer delineates the principal climate feature: the summer drought, which in turn, determines the ephemeral nature of the flows of the wetlands formed in the area.

The Valencia municipality is one of the districts in the Valencia province that attracts many people to come to the city and settle in the metropolitan boundaries. According to the office of statistics (2008), the city of Valencia has a total population of 819067 inhabitants (Table 1) and it is the centre of an extensive metropolitan area. This represents 18% of the population of the Valencian community and in terms of population, the third largest city in Spain after Madrid and Barcelona.

Table 1. Demographic change in the Valencia Municipality (1981-2008)

No.	Districts → Years	1981	1986	1991	1996	2006	2007	2008	Variation 81/08 (%)
1	Ciutat Vella	35,415	30,125	27,010	24,027	25,546	25,368	25,788	-27.18
2	L'eixample	55,078	49,767	46,855	45,082	45,131	44,127	44,108	-19.92
3	Extramurs	57,701	52,713	52,448	49,670	50,686	50,076	50,171	-13.05
4	Campanar	24,348	28,228	31,178	30,220	34,708	34763	35,374	+45.29
5	La Saidia	48,931	47,466	48,824	46,830	50,191	49,320	49,489	+1.14
6	El Pla Del Real	29,804	27,912	31,545	30,401	31,616	31,369	31,547	+5.85
7	Lolivereta	55,427	51,351	51,468	48,905	50,581	50,177	50,925	-8.12
8	Patraix	43,151	46,296	51,415	54,648	59,441	58,401	58,648	+35.91
9	Jesus	44,854	47,104	51,183	50,129	53,819	53,693	54,177	+20.79
10	Qautre Carreres	67,406	66,905	68,269	67,917	75,274	74,556	75,260	-
11	Poblats Maritims	60,484	59,716	58,643	58,824	59,489	58,859	60,019	-
12	Camins Al Grau	48,035	46,697	48,151	49,151	63,372	63,367	64,619	+34.52
13	Algiros	34,921	36,286	40,823	41,654	41,781	40,803	40,677	+16.48
14	Benimaclet	23,512	24,837	27,891	29,253	31,062	30,448	30,789	+30.95
15	Rascanya	43,120	42,791	44,117	43,758	51,860	51,933	53,187	-
16	Benicalap	36,138	35,154	36,941	38,749	42,607	42,843	44,015	-
17	Pobles Del Nord	6,476	6,129	6,074	6,218	6,104	6,271	6,493	-
18	Pobles Del'Oest	11,978	12,262	12,233	12,324	13,841	13,905	14,183	+18.41
19	Pobles Del Sud	17,969	17,680	17,915	18,923	20,287	20,387	29,598	+14.63
	Total	**744,748**	**729,419**	**752,983**	**746,683**	**807,396**	**800,666**	**819,067**	

Office of the Statistics, Valencia, 2008

Potential vegetation (Costa, 1982) is assumed to be formed by *coscojares* (dominated by *Quercus coccifera*). Most of the area is now occupied by Mediterranean cultivations, where citrus fields and vegetable crops are found. Urban, residential and paved surfaces are predominant features of the study area.

Including Valencia, the Mediterranean region has shown an intensive process of land use/land cover changes in the last 50 years (Pascual Aguilar, 2002). The land cover transformations are mainly produced by contemporary socio-economic changes that have produced a drift from traditional agriculture to industrial and tourism economies, reinforced by population's trends to concentrate in cities or large urban regions (Pascual Aguilar, et al., 2006). The increasing development pressure allowed Valencia to become one of the fastest growing major cities in Spain. This rapid urban expansion has substantially altered the composition and spatial structure of the landscape. The resulting strong urban pressure in recent years is threatening natural characteristics with economic and life quality consequences. Land use/land cover change detection and modeling urban growth in this area may provide useful insights about the characteristics of this phenomenon and taking remedial actions.

1.4 Structure of the Thesis

The thesis work is organized into five sections in which the first section deals with the introduction and statement of the problem, research objectives, research questions, description of the study area and organization of the paper. The second part contains review of related literatures where the concept of Geospatial Technologies-GIS and remote sensing, land use/land cover, urban land use dynamics, spatio-temporal urban land use/land cover pattern and urban patterns and spatial metrics are reviewed. Data and methodology, image pre-processing, classification and accuracy assessment procedures are briefly presented in the third section. The fourth section deals with results and discussion including data presentation and data analysis consisting of nature, extent and rate of land cover change maps and statistics, spatial analysis of change detection and patterns, spatial transition of land use/cover change analysis using spatial metrics, temporal patterns of land use/cover changes and limitations of the are mentioned in this section. Finally, conclusions of the study are presented in the fifth section.

2. REVIEW OF RELATED LITERATURE

In order to analyze land use/land cover changes and monitor spatial and temporal dynamics at various scales, it is important to review historical background and concepts and related works done so far with particular emphasis on land use/land cover changes applying Geospatial Technologies. This section highlights review of related literature focusing on GIS, remote sensing, their applications for spatio-temporal land use/cover studies. Furthermore, the techniques of spatial metrics and its application for spatial pattern and structural analysis of urban dynamics have been reviewed under the following sub-topics.

2.1 Geospatial Technologies-GIS and Remote Sensing

The modern usage of the term 'Remote Sensing' has more to do with the technical ways of collecting airborne and space borne information. Earth observation from airborne platforms has a hundred and fifty years old history although the majority of the innovation and development has taken place in the past three and half decades. The first Earth observation using a balloon in the 1960s is regarded as an important benchmark in the history of remote sensing. Since then platforms have evolved to space stations, sensors have evolved from cameras to sophisticated scanning devices and the user base has grown from specialized cartographers to all rounded disciplines. It was the launch of the first civilian remote sensing satellite in the late July 1972 that paved the way for the modern remote sensing applications in many fields including natural resources management (Lillesand et al., 2004).

Meanwhile, the Landsat Program is a series of Earth-observing satellite missions jointly managed by NASA and the US Geological Survey to provide, for the first time, a global and continuous remote sensing of the earth's resources. Since 1972, Landsat satellites have collected information about Earth from space. This science, known as remote sensing, has matured with the Landsat program. The products of this programme are freely accessible and of immense value to many potential users.

Landsat sensors have a medium spatial-resolution and have been providing multispectral images of the earth continuously since the early 1970s. This unparalleled data archive gives scientists and global change researchers the ability to assess changes in earth's landscape. The first was launched in 1972 and the most popular instrument in the early days of Landsat was the MultiSpectral Scanner (MSS) and later the Thematic Mapper (TM) and the latest satellite in the series is Enhanced Thematic Mapper (ETM+). There are about 7 Landsat satellites of MSS, TM and ETM+. These satellites have a band range from 4 to 8 for MSS (earliest) and ETM+ of the latest Landsat series respectively. The satellites have a temporal resolution of 18 for the earlier MSS Landsat 1 and 2 sensors and 16 days for others thereafter[1].

Today the increased dissemination and utilization of geographic data is the result of an unprecedented growth on the geospatial technologies- referring the three sciences- Global Positioning System (GPS), remote sensing and Geographic Information System (GIS). These technologies allowed users to easily access geographic information and to deal with geospatial data in a variety of activities with different levels of complexity (Bossler, 2002). Geographic information and imaging systems visually portray layers of information in new ways to reveal relationships, patterns and trends. Software vendors such as ESRI and ERDAS provide the functions and tools needed to store, analyze and display information about places. A Geographic Information System (GIS) is a computer based tool for mapping and analyzing features of events on Earth. GIS technology integrates common database operations, such as query and statistical analysis with maps. GIS manages location-based information and provides tools for display and analysis of various statistics. It allows to link databases and maps to create dynamic displays and meaningful interrelations. In addition, it provides tools to visualize queries and overlay those databases in ways not possible with traditional spreadsheets. These special capabilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes and planning strategies of various phenomenon that are tied with space[2]. Remote sensing, on the other hand, is a science of making measurements of Earth using sensors on airplanes or satellites. These sensors collect data in the form of images and provide specialized capacities for

[1] http://landsat.gsfc.nasa.gov/
[2] http://www.gis.com/

manipulating, analyzing and visualizing those images (Nicholas, 2008). Hence, remote sensing integrated with GIS allows us mapping and monitoring land use and land cover dynamics. Land use/land cover change analysis is an important tool to assess global change at various spatial-temporal scales (Lambin, 1997). With the launching of Landsat satellite sensors in the early 1970’s, satellite imageries have been seen as a useful tool for monitoring environments and enabled making decisions of spatially oriented. Similarly, remotely sensed data of the earth may be analyzed to extract useful thematic information pertaining to the environment including urban, agriculture, forest, wetlands or water surfaces.

2.2 Land Use/Land Cover: Concepts and Definitions

In order to get a notion of land cover dynamics, it is useful to review on the concepts the terms. Land use /land cover change is a general term for the human modification of the Earth’s terrestrial surface. Although humans have been modifying land to obtain food and other essentials for thousands of years, current rates, extents and intensities of land use /land cover change are far greater than ever in human history, driving unprecedented changes in ecosystems and environmental processes at local, regional and global scales. Today, land use /land cover changes encompass the greatest environmental concerns of human population including climate change, biodiversity depletion and pollution of water, soil and air. Currently, monitoring and mediating the adverse consequences of Land use /land cover change while sustaining the production of essential resources has become a major priority of researchers and policy makers around the world (Erle and Pontius, 2007).

In studying the land use/land cover dynamics, it is quite useful to have an overview of the concepts and working definition of these terms. Hence, land cover refers to the “physical and biological cover over the surface of earth, including water, vegetation, bare soil, and/or artificial structures”. Land use is a more complicated term that can be defined in terms of disorders of human activities on the natural environment such as agriculture, forestry and building construction. These activities alter land surface processes including biogeochemistry, hydrology and biodiversity processes. Social scientists and land managers define land use more broadly to include the social and economic purposes and contexts for and within which lands are managed (or left unmanaged) such as subsistence versus commercial agriculture, rented versus owned or private vs. public land (Turner, 2002).

Meanwhile, land use change models are tools to support the analysis of the causes and consequences of land use dynamics. According to Verburg, et al., (2004), scenario analysis with land use models can support land use planning and policy. To date, numerous land use models are available that are developed from different disciplinary backgrounds. Models of land use change are tools to support the analysis of the causes and consequences of land use/land cover changes in order to better understand and functioning of land use system and to support land use planning and policy. Models are useful to disentangle the complex suite of socio-economic and biophysical forces that influence the rates and spatial pattern of land use and land cover change and for estimating and predicting the impacts of land use changes. Furthermore, models can support the exploration of future land use changes under different scenario conditions. Summarizing land use models are useful and reproducible tools, supplementing our existing mental capabilities to analyze land use change and to make more informed decisions (Costanza and Ruth, 1998).

2.3 Land Use and Land Cover Change Studies

Changes in land cover and the way people use the land have become recognized since the mid 1980s as important global environmental changes in their own right (Turner, 2002). Scientific research community called for substantive study of land use changes during 1972 Stockholm Conference on the Human Environment, and again 20 years later, at the 1992 United Nations Conference on Environment and Development (UNCED). At the same time, International Geo-sphere and Biosphere Programme (IGBP) and International Human Dimension Programme (IHDP) co-organized a working group to set up research agenda and promote research activity for land use /land cover changes. The working group suggested three core subjects for land use /land cover change research, such as situation assessment, modeling and projecting and conceptual scaling. The ultimate goal of global change study was to assess the impacts under each possible scenario and suggest preventive actions against the adverse environmental consequences. The focus was the adverse impact of these regional and global changes on society and environment. Empirical studies by researchers from diverse disciplines found that land use /land cover and its change had become key to many diverse applications such as environment, forestry, hydrology, agriculture (Li and Yeh, 1998), geology and ecology (Weng, 2001). These applications referred to urban expansion, deforestation, crop land loss, water quality change, soil degradation etc. At the same time, in the past decades, according to Lambin, (1997), a major international initiative to study land use change, the land use and land cover project had gained great impetus in its efforts to understand driving forces of land use change (mainly through comparative case studies)., developed diagnostic models of land use change and produce regionally and globally integrated land use models. These efforts have stimulated the interest of researches to apply various techniques to detect and further model environmental dynamics at different levels including local, regional and global scales.

Historical changes in land use types such as urban expansion, agricultural land loss and forest cover change were addressed in different studies. Houghton (1994) pointed out; the major reason of land use change was to increase the local capacity of lands to support the human enterprise. Yet, together with the positive changes- i.e., those that made land more productive, there were also unforeseen impacts that could reduce the availability of land to sustain the human enterprise. Nowadays, localized changes around the world added up to massive impacts. Thus, it could be argued that even modest changes in land use had some unintended consequences. So it is necessary to discuss the impacts of land use changes on society, environment and economy for sustainable future.

The techniques of GIS and satellite remote sensing had been widely applied on detecting land use /land cover changes especially urban expansion (Weng, et al., 2003, Prenzel, 2004; Lopez and Bocco, 2001), urban planning (Li and Yeh, 1998) and cropland loss (Li and Yeh, 2004). There are various ways of approaching the use of satellite imagery for determining land use change in urban environments. Yuan, et al. (1998) divide the methods for change detection and classification into pre-classification and post-classification techniques. The pre-classification techniques apply various algorithms including image differencing and image rationing to single or multiple spectral bands, vegetation indices (NDVI) or principal components, directly to multiple dates of satellite imageries to generate “change” vs. “no-change” maps. These techniques locate changes but do not provide information on the nature of change (Ridd and Liu, 1998; Singh, 1989; Yuan, et al., 1998). On the other hand, post classification comparison methods use separate classifications of images acquired at different times to produce difference maps from which “from-to” change information can be generated (Jensen, 2004).

Change detection is the process of identifying differences in the state of an object or phenomenon by observing it at different time series (Singh, 1989). It is an important process in monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution and patterns spatial attributes. Macleod and Congalton, (1998) list four aspects of change detection which are important when monitoring natural resources:

i. detecting the changes that have occurred
ii. identifying the nature of the change
iii. measuring the area extent of the change
iv. assessing the spatial pattern of the change

The basis of using remote sensing data for change detection is that changes in land cover result in changes in measurement values which can be remotely sensed. Techniques to perform change detection with satellite imagery have become numerous as a result of increasing adaptability in manipulating digital data and increasing computer power. Post-classification comparison and multi-date composite image change detection are the two most commonly used methods in change detection (Jensen, 1996). GIS and remote sensing based change detection studies have predominantly focused on providing the knowledge of how much, where, what type of land use and land cover change has occurred.

2.4 Urban Land Use Dynamics

Now a day, urbanization has become an environmental problem of global importance. Despite the few percentage distribution and coverage of geographic space of urbanized land, the impacts of the process of urbanization on biodiversity, ecosystem fluxes and environmental quality are profound and these days it gets much attention by scholars from diverse fields, (Breuste, et al., 1998; Pickett, et al., 2001). Urban growth affects the ecology of cities in a number of ways, such as eliminating and fragmenting native habitats, modifying local climate conditions and generating anthropogenic pollutants. It is widely recognized that the spatial pattern of a landscape affects ecological processes (Wu and Loucks, 1995). Similarly, tremendous urban expansion with high inflow of population from the local or distant places and dynamic urban changes processes in their morphology, expansion of impervious surface and conversion of productive lands in and around urbanized area, affect natural and human systems at all geographic scales. Deteriorating conditions of urban crowding, housing shortages and lack of infrastructure, as well as increasing urban expansion on fertile lands highlights much attention for sustainable and effective management and planning of urban areas. Recently, innovative approaches to urban land use planning and management such as sustainable development and smart growth has been proposed and discussed (Kaiser, et al., 1995).

2.5 Application of Remote Sensing on Urban Dynamics Study

As mentioned in Herlod, eta al., (2005), for decades the visual interpretation of aerial photography of urban areas has been based on the hierarchical relationships of basic image elements. A number of urban remote sensing applications to date have shown the potential to map and monitor urban land use and infrastructure and to help estimate a variety of socio-economic data (Jenson and Cowen, 1999). However, much of the expert knowledge of the human image interpreter was lost in the transition from air photo interpretations to digital analysis of satellite imagery.

It is well known that the great strength of remote sensing is that it can provide spatially consistent data sets that cover large areas with both high detail and high temporal frequency, including historical time series. This has been becoming more effective with the emerging sensors that provide high spectral, spatial and temporal resolution data to researchers. Meanwhile, mapping of urban areas has been accomplished at different spatial scales, e.g. with different spatial resolutions, varying coverage or extent of mapping area and varying definitions of thematic mapping objects. Global and regional scale studies are often focused on mapping just the extent of urban areas (Schneider, et al., 2001). A basic difficulty of these efforts encounter relates to the indistinct demarcation between urban and rural areas on the edges of cities. Remote sensing provides an additional source of information that more closely respect the actual physical extent of a city based on land cover characteristics (Weber, 2001). However, the definition of urban extent still remains problematic and individual studies must determine their own rules for differentiating urban rural land (Herold, et al., 2003).

Considering the recent improvements in spatial, spectral, and temporal resolution, remote sensing technology can provide special advantages on studying growth and land use/land cover change processes and analysis of the growth pattern and their fragmentations (Howes, 2001). Remote sensing and spatial datasets obtained through remote sensing are consistent over great areas and over time. They provide information at a grater variety of geographic scales with a greater degree of detail. The information derived from remote sensing can help describe and model the urban environment, leading to an improved understanding that benefits applied urban planning and management (Longley and Mesev, 2000; Longley, et al., 2001).

2.6 Spatio-Temporal Urban Land Use/Land Cover Pattern

Understanding the evolution of urban systems and addressing questions regarding changes in the spatio-temporal patterns of intra- and inter-urban form are still primary objectives in urban research. Remote sensing, although challenged by the spatial and spectral heterogeneity of urban environments, seems to be a suitable source of reliable information about the multiple facets of urban environment (Jensen and Cowen, 1999; Herlod, et al, 2003). According to Herold, et al, (2005), the spatial and temporal detail provided by space and airborne remote sensing platforms have yet to be broadly applied for the purposes of developing, understanding, representing and modeling of the fundamental characteristics of spatial processes.

To understand spatial and temporal patterns in the built up or non-built up environments a framework needs to be adapted to see changes. There are essentially two perspectives from which to view spatio-temporal urban patterns (Figure 2). The traditional perspective follows a deductive top-down perspective: isolating urban structures as the outcomes of pre-specified processes of urban changes (from process to structure). This point of view is common in the fields of planning, geography and economics. This perspective has been criticized for its slight representation of the spatial and temporal complexities of urban dynamics. Early demographic and socioeconomic research was limited by the ability to conduct detailed spatio-temporal pattern analysis at anything other than aggregate levels, leading to conclusions based on a top-down chain of causality. However, current developments generated significant contributions and raised compelling questions regarding urban theory, but one question persists: "how do cities form over time"? More recent studies within these fields of urban research have started to address dynamics (White, et al, 2001, and Batty, 2002). Research has become more focused on isolating the drivers of growth rather than solely the emerging geographic patterns. While new urban models have provided insight into dynamics, a deeper understanding of the patterns and processes associated with urbanization is still limited by the availability of suitable data and the lack of compatible theory (Longley and Mesev, 2000).

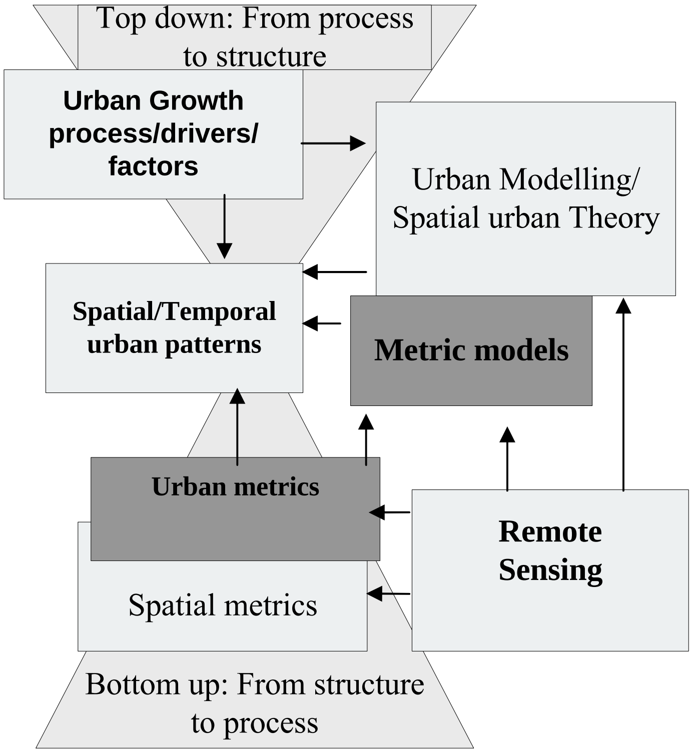

Fig. 2. Conceptual approach for studying spatio-temporal urban dynamics (adapted from Herold, et al., 2005)

Herold, et al., (2005), argued good models and good theory necessitates reliable measurements that capture spatio-temporal dynamics. This need is emphasized in the inductive, bottom up perspective. Empirical observations of actual spatial structures in spatial and temporal detail and linking changes over time to specific hypotheses about the processes involved (from structure to process) necessitates consistent available data. Remote sensing provides a freeze-frame view of the spatio-temporal pattern associated with a time series of urban changes.

2.7 Urban Patterns and Spatial Metrics

In particular, the analysis of spatial patterns and structures are central to geographic research. Spatial primitives such as location, distance, direction, orientation, linkage, and pattern have been discussed as general spatial concepts in geography (Golledge, 1995). In geography these concepts have been implemented in a variety of different ways. Under the name of landscape metrics, spatial metrics are already commonly used to quantify the shape and pattern of vegetation in natural landscapes (Gustafson, 1998; McGarigal, et al., 2002; Kadiogullari and Baskent, 2008). Landscape metrics were developed in the late 1980s and incorporated measures from both information theory and fractal geometry (Mandelbrot, 1983) based on a categorical, a patch-based representation of a landscape. Patches are defined as homogenous regions for a specific landscape property of interest, such as ‘industrial land’, ‘park’ or ‘high density residential zone’ and so on. The landscape perspective usually assumes abrupt transitions between individual patches that result in distinct polygons as opposed to the continuous ‘field’ perspective.

In analyzing environmental dynamics of forest or urban areas, landscape metrics are used to quantify the spatial heterogeneity of individual patches, of all patches belonging to a common class and of the landscape as a collection of patches. The metrics can be spatially non-explicit aggregate measures but still reflect important spatial properties. Spatially explicit metrics can be computed as patch-based indices (e.g. size, shape, edge density, patch density, fractal dimension) or as pixel-based indices (e.g. contagion) computed for all pixel in a patch (Gustafson, 1998).

According to Herold, et al, (2005), applied to fields of research outside landscape ecology and across different kinds of environments (in particular, urban areas), the approaches and assumptions of landscape metrics may be more generally referred to as ‘spatial metrics’. In general, spatial metrics can be defined as measurements derived from the digital analysis of thematic-categorical maps exhibiting spatial heterogeneity at a specific scale and resolution. This definition emphasizes the quantitative and aggregate nature of the metrics, since they provide global summary descriptors of individual measured or mapped features of the landscape (patches, patch classes, or the whole map). Furthermore, the metrics always represent spatial heterogeneity at a specific spatial scale, determined by the spatial resolution, the extent of the spatial domain and the thematic definition of the map categories at a given point in time. When applied to multi-scale or multi-temporal datasets, spatial metrics can be used to analyze and describe change in the degree of spatial heterogeneity (Wu, et al., 2000; Herold, 2003). Spatial metrics can be used to interpret the localized implications of different model scenarios. Similarly, spatial metrics can also used to define, rather than just interpret growth scenarios, as they can help represent locally detailed alternative spatial configurations. The calculated metrics allow having an overview of heterogeneity and spatial differentiations of patches in a landscape and a dynamic environment.

3. DATA AND METHODOLOGY

This section describes the data and methods that were applied in data acquisition, pre-processing (geo-reference and geometric correction), processing, presentation and analysis of data with a view to achieve the designed objectives and the research questions posed. This allowed us analysis of change and to draw conclusion on the spatio-temporal land use land cover dynamics in the municipality. Fig. 3 depicted the flow chart how the research data, methods and analysis were organized in a brief way.

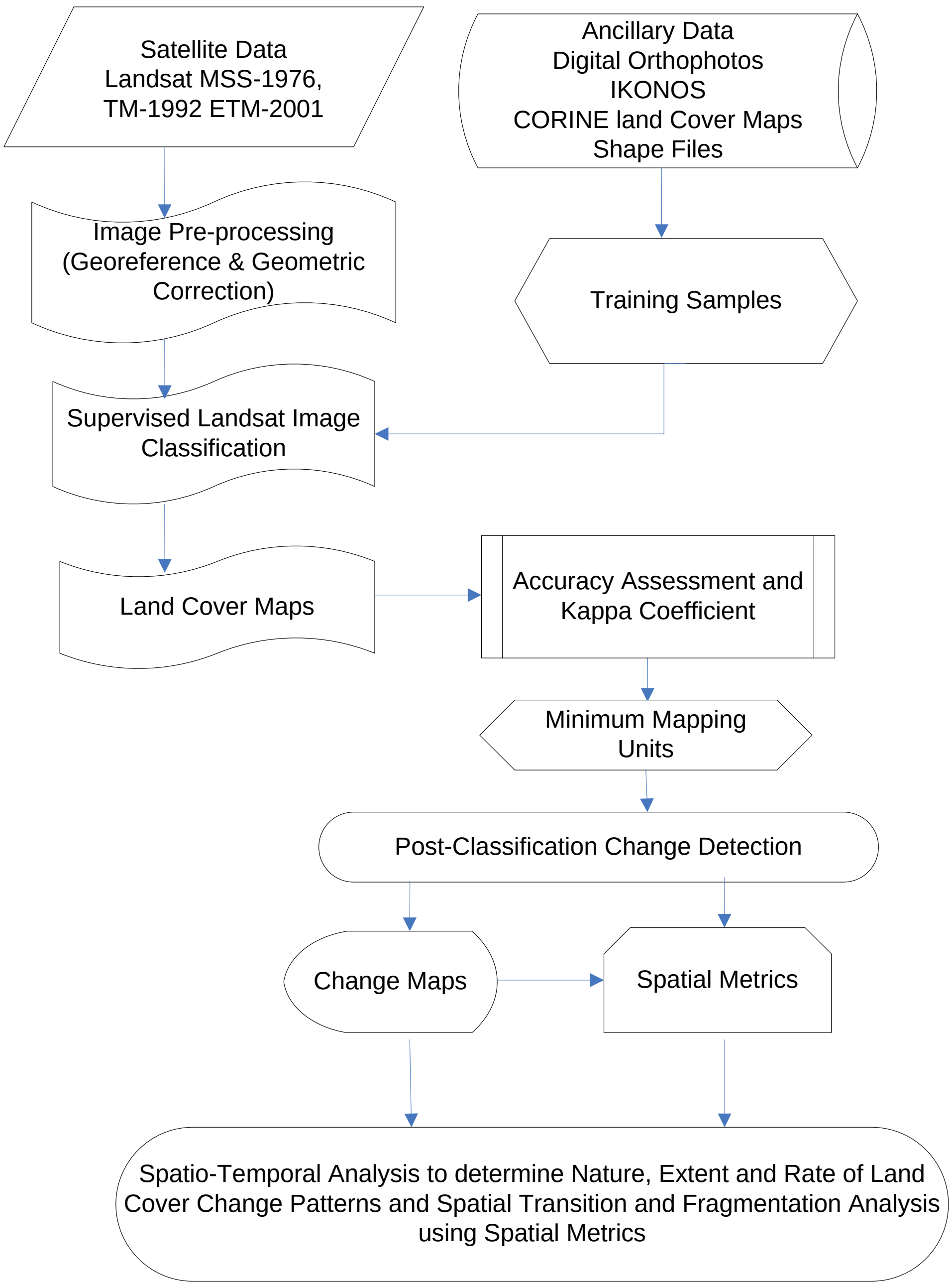

Fig. 3. The flow chart of the research data and methodology

3.1 Data

3.1.1 Landsat Data

The data that has been used for studying the municipality level spatio-temporal land use/land cover change include three historical Landsat satellite images covering Valencia municipality for the past 25 years (1976-2001). These images included one 57m resolution Landsat MSS image (1976) and two 30m resolution Landsat TM/ETM images from 1992 and 2001 (Table 2 and Fig. 3). These satellite images were obtained from the Global Land Cover Facility University of Maryland[3].

Table 2. Description of Landsat image data

Reference year	Sensor	Resolution	WRS: P/R	Date of Acquisition
1976	Landsat MSS	57 m	2:214/032	29-07-1976
1992	Landsat TM	30 m	2:199/033	20-04-1992
2001	Landsat ETM	30 m	2:199/033	08-06-2001

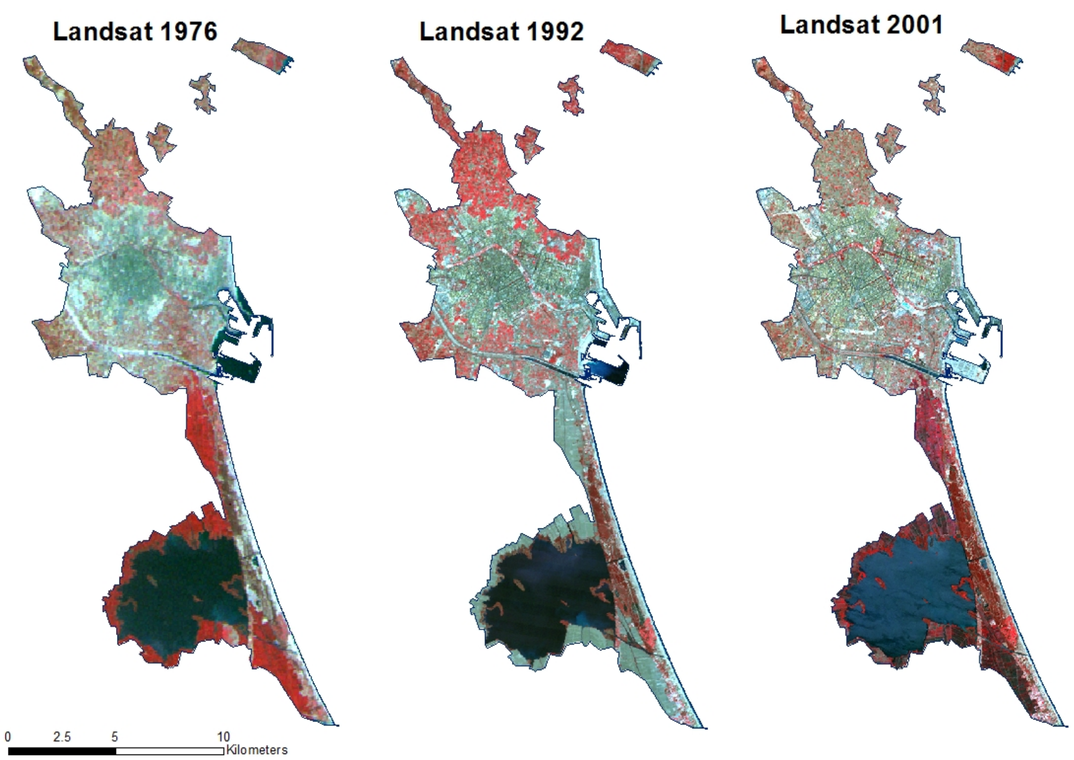

Fig. 4. RGB composite Landsat images used for classification

[3] http://glcf.umiacs.umd.edu/

3.1.2 Reference Data

In this multitemporal land cover dynamic study, it was necessary to employ a variety of methods to develop reference data sets for training samples and accuracy assessment. It is apparent that ancillary data such as high resolution imageries and existing map of the study area were essential for classifying and assessing the accuracy of the classification. The study relied mainly on high resolution orthophoto with a scale of (1:25000) from 1980, 1992 and 2002, sub-sheet IKONOS and Google Maps as reference for classification and assessment. The existing land cover map of the study area which was provided by local mapping agency-Valencia Cartographic Institute was also further referred in this study. Consequently, a number of cartographic data including CORINE Land Cover map of the region at original scale of 1:100000 for years 1990 and 2000, Land Type for Management and Road networks and district boundaries- for scene clipping were constructed as GIS layers from diverse sources. All these ancillary data were used to enhance image classification, accuracy assessment and change analysis.

3.2 Tools

In order to store, analyze and display information, software from ESRI and Leica Geosystems were employed. Hence, both ArcView/GIS 9.2 and ERDAS Imagine 9.1 were used to extract land use/land cover information and further analysis of relationships, patterns and trends in a multi-temporal approach. Furthermore, open source gvSIG- GIS client software was used for visualization of raster[4]. In order to determine spatial metrics and detect changes and fragmentation of land covers, public domain statistical package FRAGSATS 3.3 (McGarigal, et al., 2002) software was used [5]. Besides, Microsoft windows accessories for tabulations and graphical representations were used to present describe and analyze land use/land cover dynamics and trends of changes that were undertaken during three periods.

[4] http://www.gvsig.gva.es/
[5] http://www.umass.edu/landeco/research/fragstats/fragstats.html

3.3 Georeference and Geometric Correction

In order to prepare the multitemporal satellite images for accurate change analysis and detection, the Landsat images were pre-processed using standard procedures including geo-referencing and geometric correction. The European Datum 1950 (D_European_1950) was used as the coordinate system. Subsets of Landsat satellite images were rectified using orthophotos with UTM projection Zone 30 (ED_50 datum) using first order polynomial method and nearest neighbor image re-sampling algorithm. A total of 20 Ground Control Points (GCPs) were used to register the ETM image subset with the rectification error less than 1 pixel. Subsequently, Landsat TM and MSS images were registered to the already registered ETM images through image-to-image registration techniques with rectification error of less than 0.5 pixels. Rectified digital orthophotos were used in the process and this allowed direct comparison of features between the images and orthophotos during the selection of training samples for use in image classification and accuracy assessment of classified maps. In performing this image pre-processing, ERDAS Imagine Version 9.1, was used.

3.4 Land Cover Classes

Studies of land use and land cover structure change usually needs development and definition of more or less homogeneous land use/land cover units before the analysis is started. These have to be defined and spatially differentiated using the available data sources (e.g. remote sensing) and any other relevant information and local knowledge. Hence, the land cover classes used in this research are defined based on the CORINE Land Cover used for the existing land cover for 2000.

CORINE land Cover is a map of the European environmental landscape based on the interpretation of satellite images. It provides comparable digital maps of land cover for each country for much of Europe. This has been useful for environmental analysis and for policy makers. The acronym CORINE stands for *Coordination of Information on Environment*. The European Union established CORINE in 1985 to create pan-European database on land cover, biotopes (habitat), soil maps and acid rain. The land cover project in CORINE programme works with land cover nomenclature with three levels: first level having five headings; second level having fifteen headings and third level having forty-four headings (Appendix 1). It has a working scale of 1/100000 with a minimum mapping unit of 25 hectare[6]. In so doing, initially, 15 land cover classes were selected and these were further grouped into six classes as shown in Table 3 below. Hence, the subsequent spatial and temporal land use/land cover change analyses are based on these classes.

Table 3. Land cover nomenclature based on CORINE

Land cover classes	**Descriptions**
Built up(Artificial) surfaces	This classes includes urban fabric, industrial, commercial, transport units and other related built up areas of non agricultural, vegetated areas
Agricultural areas	Crop, pasture, irrigated land and plantation are included in this class, heterogeneous agricultural areas and agro-forestry areas
Forest, shrubs and semi-natural areas	It comprises forest land, shrub and other mixed forest land, herbaceous vegetation associations
Open/barren area	Open spaces with little or no vegetation, beaches, dunes sands, bare rocks, sparsely vegetated areas
Wetlands	Inland and maritime wetland
Water bodies	Water courses, water bodies, sea and ocean areas, coastal lagoons

[6] http://www.eea.europa.eu/

3.5 Image Classification

After the images were goeoreferenced and geometrically rectified, image clipping was performed. This pre-process was performed using spatial analyst tool on a sub-scene from the full image on the basis of a frame covering the municipality. These pre-processing tasks allowed us to export the satellite images to the ERDAS Imagine for classification and extracting land cover information. Image classification and interpretation was performed using ERDAS Imagine 9.1. Using reference images (e.g. digital orthophotos (1980, 1992 and 2002), IKONOS and Google Maps) and the existing CORINE land cover maps for 1990 and 2000; training samples were gathered from more than 130 points as signatures for each Landsat satellite images. The training points were proportionally distributed to each cover types with at least 15 points per cover type. For the supervised classification of 1976 image, the 1980 orthophoto and its unsupervised classification map were used to create ground signatures. Similarly, the orthophotos of 1992 and the 1990 CORINE land cover maps were used to create ground control signatures for the supervised classification of 1992. In a similar way, the digital orthophoto of 2002 and sub-sheet IKONOS images of 2002 and the 2000 CORINE land cover maps were used to create ground signatures for the supervised classification of 2001 Landsat ETM image. These signatures were then used in a supervised classification method. Land use/land cover was mapped by means of visual interpretation of satellite images. The classification was categorized in to CORINE Land Cover nomenclature and consists of six classes for each time period (Table 3). The major classes are artificial/built up areas, agricultural areas, forest, shrubs and semi-forest areas, open/barren surface, wetlands and water bodies.

From the supervised classification methods in ERDAS Imagine, the parallelepipeds-maximum likelihood (Para-ML) classification algorithm was used to produce the land cover maps. The Para-ML method combines parallelepiped and maximum likelihood classification methods, and uses a decision rule to evaluate each pixel. The parallelepiped classification is based on a set of lower and upper threshold reflectance determined for a signature on each band. To be assigned to a particular class, a pixel must exhibit reflectance within this reflectance range for every band considered. Pixels that are assigned to more than one class are then passed to the maximum likelihood decision rule for assignment to a single class. Those classes that couldn't be identified in any other way were manually digitized over the images. The final land cove maps produced using these procedures enabled spatio-temporal change analysis and pattern through change maps and spatial metrics.

3.6 Accuracy Assessment

Land cover maps derived from classification of images usually contain some sort of errors due to several factors that range from classification techniques to methods of satellite data capture. Hence, evaluation of classification results is an important process in the classification procedure. In so doing among the common measures used for measuring the accuracy of thematic maps derived from multispectral imagery, error/confusion matrix was used (Congalton and Green, 1999). An error matrix is a square assortment of numbers defined in rows and columns that represent the number of sample units assigned to a particular category relative to the actual category as confirmed on the ground. The rows in the matrix represent the remote sensing derived land use map, while the columns represent the reference data that were collected from field work. These tables produce many statistical measures of thematic accuracy including overall classification accuracy, percentage of omission and commission error and kappa coefficient-an index that estimates in the influence of chance (Congalton and Green, 1999).

Error of omission is the percentage of pixels that should have been put into a given class but were not. Error of commission indicates pixels that were placed in a given class when they actually belong to another. These values are based on a sample of error checking pixels of known land cover that are compared to classification on the map. Error of commission and omission can be expressed in terms of user's accuracy and producer's accuracy. User's accuracy represents the probability that a given pixel will appear on the ground as it is classed, while producer's accuracy represents the percentage of a given class that is correctly identified on the map. On the other hand, Kappa coefficient is a measure of the interpreter agreement. The Kappa statistics incorporates the off-diagonal elements of the error matrices (i.e., classification errors) and represents agreement obtained after removing the proportion of agreement that could be expected to occur by chance. One of the problems with the confusion matrix and the kappa coefficient is that it does not provide a spatial distribution of errors (Foody, 2002).

The land cover classification accuracy assessment was based on 270 stratified random sampling points, comparison between each classified images, and comparison with a suite of orthophotos, Google Earth Imageries and existing land cover maps. After accuracy assessment, all images were vectorized into polygons. These polygon coverages were then pre-processed to eliminate areas less than 1 ha as a Minimum Mapping Unit for spatial landscape analysis.

4. RESULTS AND DISCUSSION

This section presents the results and discussion of the generated land cover maps from classification of Landsat images. It includes assessment of the maps' accuracy, analysis of the nature, extent and rate of land cover change maps and statistics. Besides, spatial analysis of change detection and patterns, spatial transition of land use/land cover change analysis using spatial metrics and temporal patterns and configuration of land use/land cover changes are also presented in subsequent sections. Issues of population dynamics and Land Type for Management in the municipality are also highlighted for interpretation and analysis of land use/land cover dynamics and pattern in the study area.

4.1 Classification Accuracy Assessment

Evaluation of classification results is an important process in satellite image classification procedure. In doing so confusion/error matrices were used. It is the most commonly employed approach for evaluating per-pixel classification (Lu and Weng, 2007). The accuracy was assessed with cross-validation against digital orthophoto for the multi-dates, sub-sheet IKONOS and Google Earth Imageries. Using these reference data and the classified maps, confusion matrices were constructed (Table 4, 5 and 6) for the three periods. The resulting Landsat land use/cover maps of the three periods of 1976, 1992 and 2001 had an overall map accuracy of 84.1%, 86.5% and 88.6 % respectively. This was reasonably good overall accuracy and accepted for the subsequent analysis and change detection. User's accuracy of individual classes ranged from 71% to 100 % and producer's accuracy ranged from 58 % to 100%.

Kappa statistics/index was computed for each classified map to measure the accuracy of the results. The resulting classification of Landsat land use/cover maps of the three periods of 1976, 1992 and 2001 had a Kappa statistics of 78.1%, 78.6% and 83.4% respectively. The Kappa coefficient expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification. Kappa accounts for all elements of the confusion matrix and excludes the agreement that occurs by chance. Consequently, it provides a more rigorous assessment of classification accuracy. The Kappa coefficient was calculated according to the formula given by Congalton and Green (1999):

$$K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{i+} \times X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} \times X_{+i})}$$

Where,

r = the number of rows in the error matrix

X_{ii} = the number of observations in row *i* column *i* (along the diagonal)

X_{i+} = is the marginal total of row *i* (right of the matrix)

X_{+i} = the marginal total of column *i* (bottom of the matrix)

N = the total number of observations included in the matrix

Table 4. Landsat MSS classification accuracy for 1976

	Cover Types	**Reference Map**							
		Artificial Surfaces	Agricultural areas	Forest	Open space	Wet lands	Water	Grand Total	**User's Acc. (%)**
Classified map	Artificial/Built - up Surfaces	**59**	6	1	0	0	0	66	89
	Agricultural areas	28	**180**	6	8	10	2	234	77
	Forest and semi-natural	3	9	**30**	0	0	0	42	71
	Barren/open spaces	0	4	4	**24**	0	0	32	75
	Wetlands	0	0	0	0	**40**	0	40	100
	Water	12	6	0	0	12	**252**	282	90
	Grand Total	102	205	41	32	62	254	**696**	
	Producer's Accuracy (%)	58	87	73	75	65	99		
	Over all map accuracy = 84.1%								
	Over all Kappa Index = 78.1%								

Landsat MSS image (1976) was classified for six land cover classes successfully. However, artificial surfaces comprising settlement and other built up-artificial surfaces were classified with a lower producer's accuracy (58%) than other classes. This is due to the combination of omission and commission errors particularly mixing with agricultural class. Lower producer's accuracy was also observed for wetlands due to the omission and misclassification to agriculture and some to water.

Accuracy of the MSS Landsat image is lower because it has lower spatial resolution and too coarse to study land cover of urban environment and the accuracy gets reduced due to mixed pixels. It was common to find mixed land use in urban areas within this 57m spatial resolution image. Yet, despite some evidence for both systematic commission and omission errors, watching the higher overall classification (84.1%), it was acceptable as good classification.

Likewise, Landsat TM image (1992) was classified into six classes. It indicated a better over all classification (86.5%). In classifying the third Landsat ETM image (2001), much better overall and producer's accuracy (88.6%) was achieved. The higher accuracy was achieved due to the utilization of more ancillary data in collecting training samples for classification and the season of the image during the process of classification. In general, there was some evidence for both systematic commission and omission errors resulting from the classifier side as incorrectly commits pixel of the class being sought to other classes as well when some class on the ground were misidentified as another class by the classifier.

Table 5. Landsat TM classification accuracy for 1992

	Cover Types	**Reference Map**							
		Artificial Surfaces	Agricultural areas	Forest	Open space	Wet lands	Water	Grand Total	**User's Acc. (%)**
Classified map	Artificial/Built-up Surfaces	**71**	4	3	3	0	0	81	88
	Agricultural areas	10	**212**	8	4	4	0	238	90
	Forest and semi-natural	0	3	**15**	0	0	00	18	83
	Barren/open spaces	0	0	0	**16**	0	0	16	100
	Wetlands	5	10	0	0	**18**	0	25	72
	Water	24	6	0	0	10	**270**	318	100
	Grand Total	110	235	26	23	32	270	**696**	
	Producer's Accuracy (%)	65	90	58	70	56	100		
	Over all map accuracy = 86.5%								
	Over all Kappa Index = 78.6%								

Table 6. Landsat ETM classification accuracy for 2001

	Cover Types	Reference Map							
		Artificial Surface	Agricultural areas	Forest	Open space	Wet lands	Water	Grand Total	**User's Acc. (%)**
Classified map	Artificial/Built-up Surfaces	**68**	15	3	4	0	1	91	75
	Agricultural areas	0	**194**	2	2	4	0	202	96
	Forest and semi-natural	0	3	**21**	0	0	0	24	88
	Barren/open spaces	4	0	0	**32**	0	0	36	89
	Wetlands	0	10	0	0	**30**	0	40	75
	Water	12	0	0	6	18	**282**	318	100
	Grand Total	84	222	26	44	52	283	**711**	
	Producer's Accuracy (%)	81	87	81	73	58	100		
	Over all map accuracy = 88.6%								
	Over all Kappa Index = 83.4%								

4.2 Nature, Extent and Rate of Land Cover Change Maps and Statistics

Using the approaches adopted in the methodology, land cover maps were generated for all the three years (Fig.5a, b, and c) and area estimates and change statistics are computed. Individual class area and change statistics for the three years were summarized in Table 7 and 8. In the study periods covered, the major land cover classes identified includes agriculture, urban-built up surfaces, water, forest and semi-natural surfaces, wetland and open/barren surfaces. Among all the land cover types identified, and in the three periods, agriculture and artificial-built up surfaces and water constituted the predominant type of land cover with an approximate area of 92% in their spatial extent in the region. Forest, barren and wetland accounted for 8 % of the total area of the region representing the small proportion of the land cover classification (Table 7).

Table 7. Area statistics and Percentage of the land use/cover units in 1976-2001

Land Cover Type	**1976** Area (ha)	%	**1992** Area (ha)	%	**2001** Area (ha)	%
Artificial/Built up Surfaces	3415	24.7	4042	29.4	4699	34.1
Agricultural areas	6560	47.6	6048	43.8	5493	39.9
Forest and semi-natural areas	474	3.4	435	3.1	462	3.4
Barren/open spaces	235	1.7	220	1.5	205	1.5
Wetlands	434	3.1	370	2.7	353	2.7
Water	2694	19.6	2692	19.5	2583	18.5
Total	13795	100	13795	100	13795	100

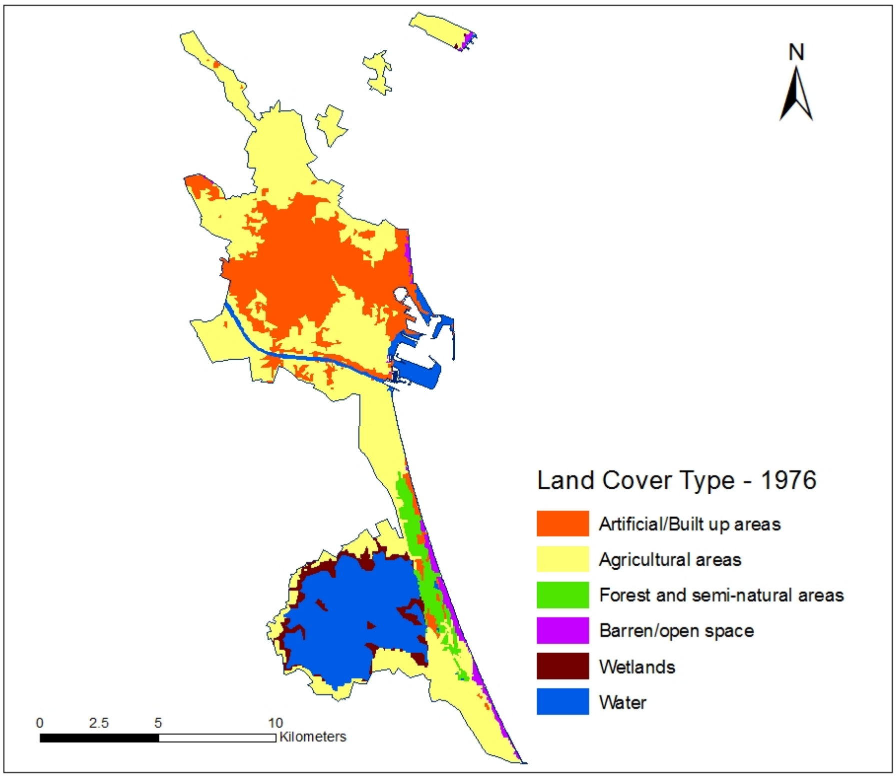

Fig. 5(a). Landsat land cover classification for 1976

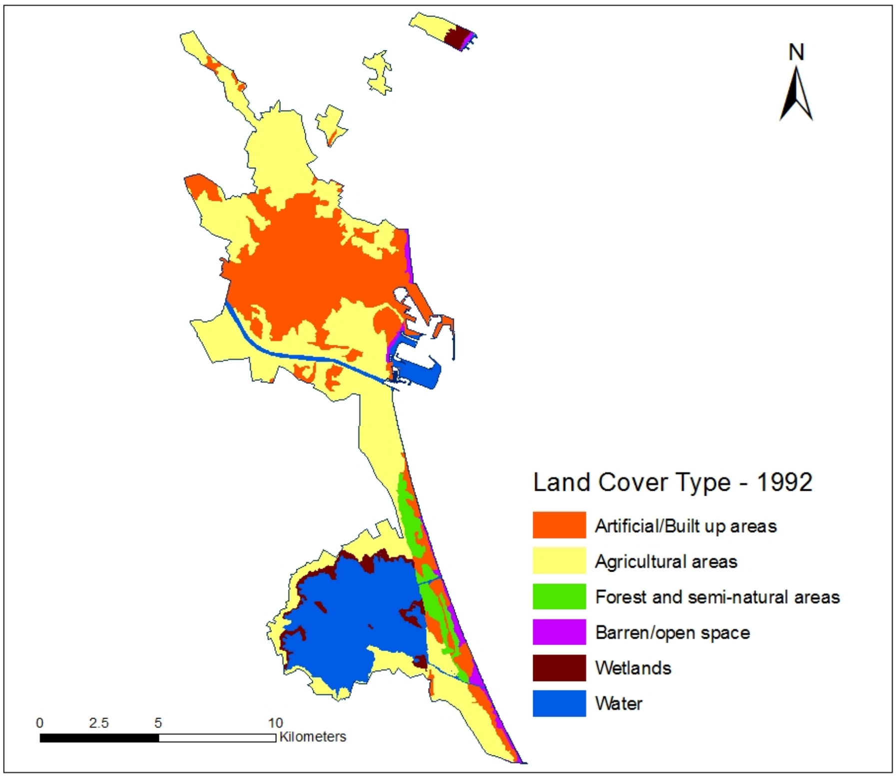

Fig. 5(b). Landsat land cover classification for 1992

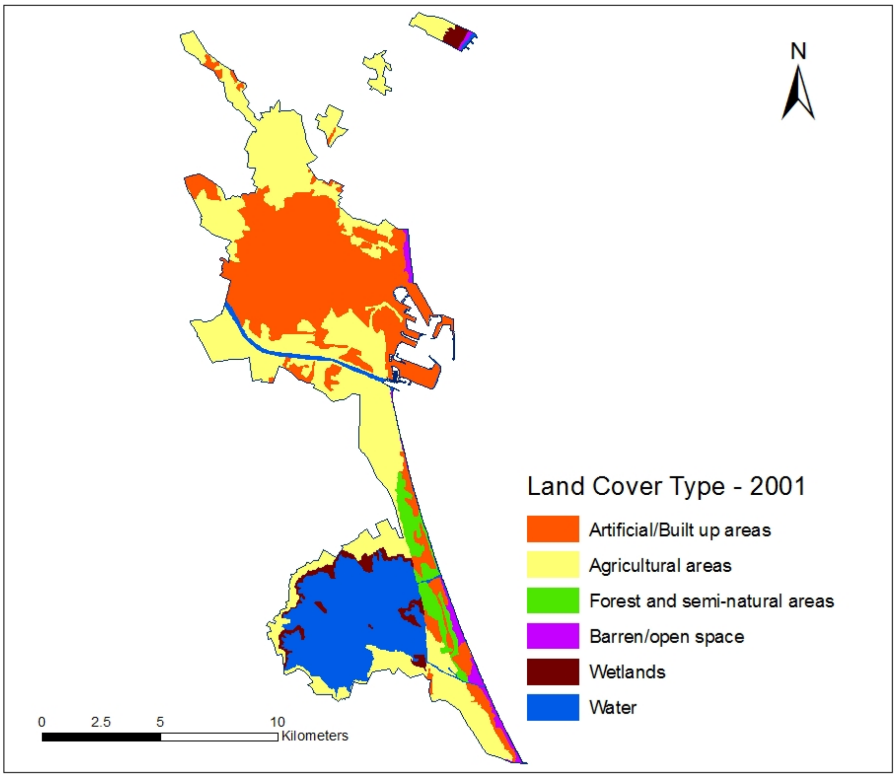

Fig. 5(c) .Landsat land cover classification for 2001

There are several ways to quantify the land cover change results. Among others, one basic method is to tabulate the total land cover changes for each land use/land cover type and examine the trends of change between the years. During the investigation periods, distinct changes have occurred on the major land use/land cover types. From 1976 to 1992, the built up environment increased approximately 627ha (18%) while agricultural land decreased 512ha (8%), forests and semi-natural areas decreased 39ha (8%), wetlands decreased 64ha (15%), open surface decreased 15ha (6%). The total area of water surface has not shown a significant change and it accounted for a percentage change of 2%. During the second period between 1992 to 2001, the built up environment increased drastically by 657ha (16%) while agricultural land continuously converted and decreased 555ha (9%), forests and semi-natural areas showed a relative increment 27ha (6%), wetlands decreased 17ha (5%), barren/open surface decreased 15ha (7%). Particularly, in this period, a huge volume of water surface has declined 109ha (4%). Urban areas/artificial surface in general increased from 1976 to 2001, by 39% with the greatest increase occurring from 1992 to 2001, 16 % within 9 years period as compared with 18% within 16 years between 1976-1992. Agriculture, wetlands, barren, forest and water decreased by 16%, 19%, 13%, 3% and 4 % respectively and mostly they were converted to built-up surfaces. The relative trends of these changes are further depicted in Fig. 6.

In order to determine the extent and rate of change in the land cover dynamics in the region, the following variables are developed and computed.

- Total area (T_a)
- Changed area (C_a)
- Change extent (C_e)
- Annual rate of change (C_r)

These variables can be described by the following formula:

$C_a = T_a(t_2) - T_a(t_1)$;

$C_e = C_a / Ta(t_1)$;

$C_r = C_e / (t_2 - t_1)$; Where t_1 and t_2 are the beginning and ending time of the land cover studies conducted.

Table 8. Overall amount, extent and rate of land cover change (1976-2001)

Land Cover Type	**1976-1992**			**1992-2001**			**1976-2001**		
	Change (Δ /ha)	Extent (%)	Rate of Δ (%/yr)	Change (Δ /ha)	Extent (%)	Rate of Δ (%/yr)	Change (Δ /ha)	Extent (%)	Rate of Δ (%/yr)
Built up Surfaces	+627	+18	+1	+657	+16	+2	+1284	+39	+1.8
Agriculture	-512	-8	-1	-555	-9	-1	-1067	-16	-1
Forest	-39	-8	-1	+27	+6	+1	-12	-3	0
Open spaces	-15	-6	0	-15	-7	-1	-30	-13	-1
Wetlands	-64	-15	-1	-17	-5	-1	-81	-19	-1
Water	-2	0	0	-109	-4	0	-111	-4	0

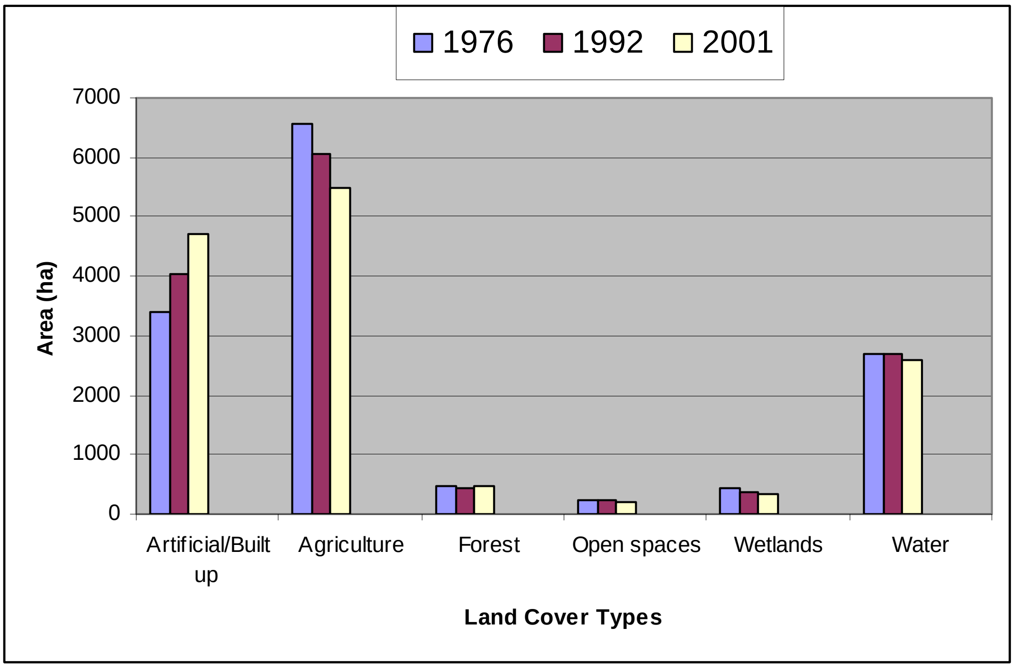

Fig. 6 Nature of relative land cover changes 1976 to 2001

Figure 6 depicted the relative land cover change trends from 1976-2001 in Valencia Municipality. The major land use of urban-built up surface had an increasing positive trend of change in its areal extent while agricultural lands decreased continuously in the three periods. There has been also an observable declining trends of change in the other land cover classes of water, open surfaces, wetland and water bodies.

The average annual rate of change in urban area as determined from the Landsat change statistics was 1% from 1976 to 1992, 2% from 1992 to 2001 and 1.8 % for the entire period of 1976 to 2001. This implies a dramatic urban expansion and change in the morphology of the city size and extents. On the other hand, agriculture and wetlands and barren areas showed an average reduction of change approximately 1% annually. The rate of change for forest and semi-natural and water surfaces classes was insignificant between 1976 and 2001. However, there had been a marked change in the proportion of water surface in the second temporal season of the study period of 1992 and 2001. The changes in the areal extent of the water surfaces was believed to be related to the huge expansion of port service and beach leisure which has converted the coastal sea zone and its adjacent areas to artificial surfaces.

In general, the change values in the Table 8 indicated that increase in built up /urban areas mainly emanated from conversion of other land covers in particular agriculture to urban land uses during the past 25 years (1976-2001) following increasing development pressure within the municipality. Besides the summary statistics, graphical representations of the classification and visual comparison offer a general insight into the relative amounts of the defined classes across the landscape and the changes observed (Figure 7).

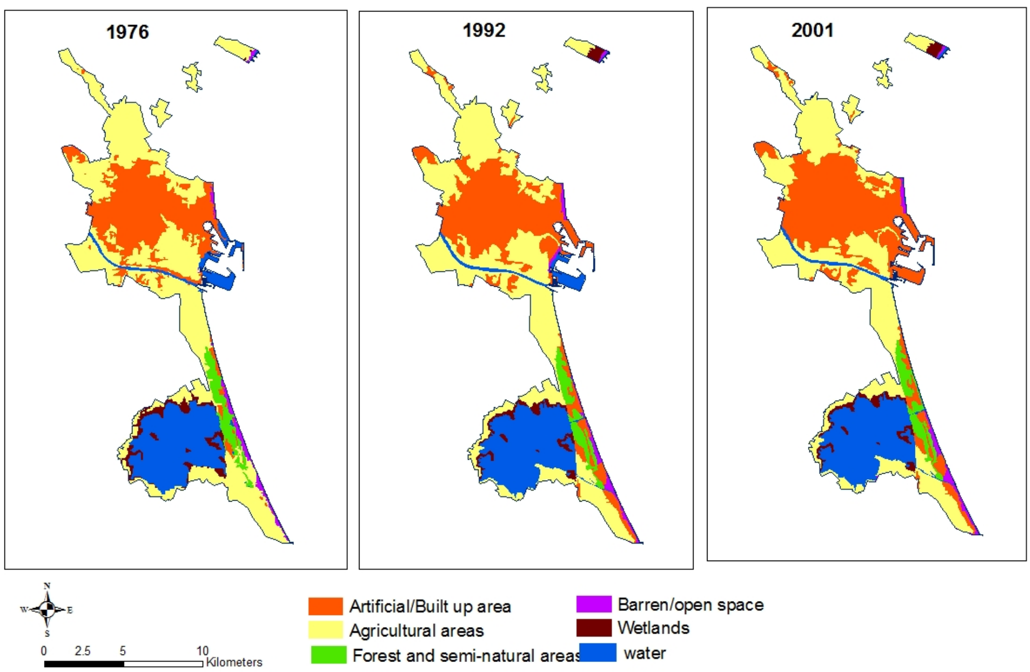

Fig.7. Land cover classification from 1976 to 2001 for Valencia Municipality

4.3 Spatial Analysis of Change Detection and Patterns

The dynamics of land use/land cover change pattern have been identified by analyzing the classified multi-temporal satellite images of 1976, 1992 and 2001. Although similar statistics could be generated for other land cover units such as districts or census tracts, the change statistics in Table 8 provides little visual exploration and analyses on the question of "where" land use/land cover changes were occurring. However, by constructing a change detection map (Fig.8a), the advantages of satellite remote sensing in spatially disaggregating the change statistics and visual display and comparison can be more fully appreciated. A multiple-date post classification comparison change detection algorithm was used to determine changes in land cover in time intervals, 1976-1992, 1992-2001 and 1976-2001. This is the most common approach to change detection (Jenson, 2004). The post classification approach provides "from-to" change information and the kind of landscape transformation that have occurred can be easily calculated and mapped. In this study, putting focus on urban expansion and pattern, the final six class land cover map has been reclassified in to built-up and non-built-up areas and then combination of "from-to" change information was derived for the built and non built up class maps. Fig.8a showed a map of the major land cover types as classified as built and non-built up and the conversion from non built-up particularly agricultural to built up/artificial surfaces in the adjacent Valencia metropolitan core.

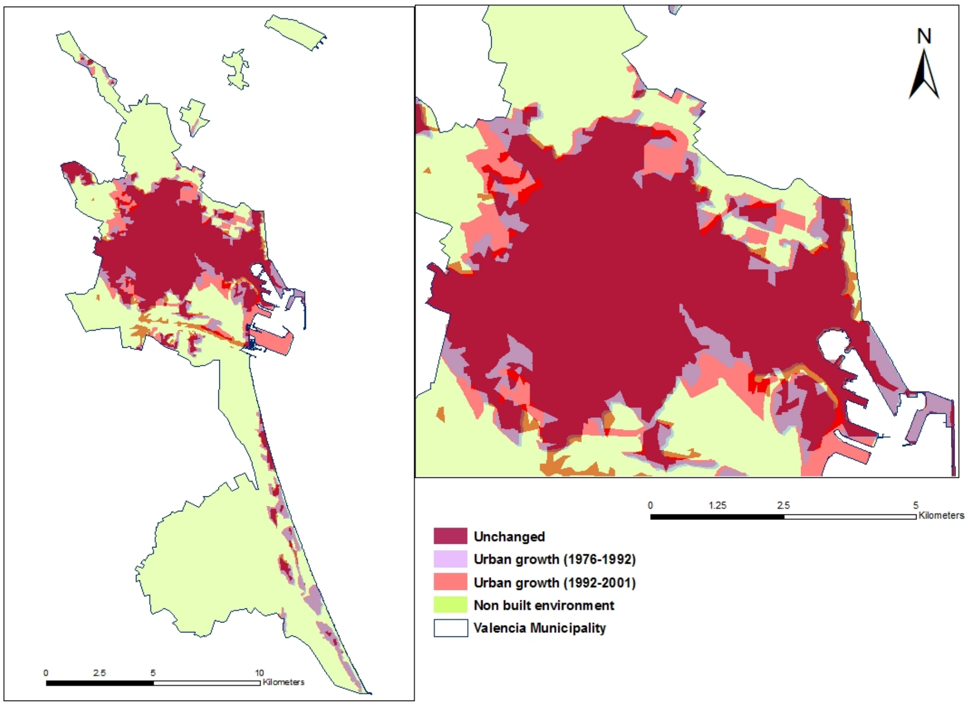

Fig.8(a). Municipality land cover change detection map showing the urban Growth from 1976 to 2001

The change detection map in Fig. 8a depicted that, rapid expansion of urbanized area within the Valencia municipality was evident over time. The map revealed that major land use/land cover changes occurred everywhere, in all direction of the city before 1992; however, in the recent classified map of 2001, the intensity was higher at the direction of North-east, North-west and South and South-west of the metropolitan core of Valencia. These areas are places of increasing development pressure and urban expansion. Expansion of the already existing urban fabrics through rapid construction sites of residential units, commercial and industrial units and road networks and pavements port and leisure facilities and other impervious surfaces all combined together leads to continuous expansion of built up surfaces in the different corners of the city. Urban growth and the loss of agricultural land were the most conversion in the area. In order to see the pattern, further GIS analysis was performed and the pattern revealed a strong relationship between the new development in urban expansion and proximity to highways (Fig.8b). With GIS buffer analysis; most of the development detected in the classification occurred within 2 km from highways particularly the recent developments.

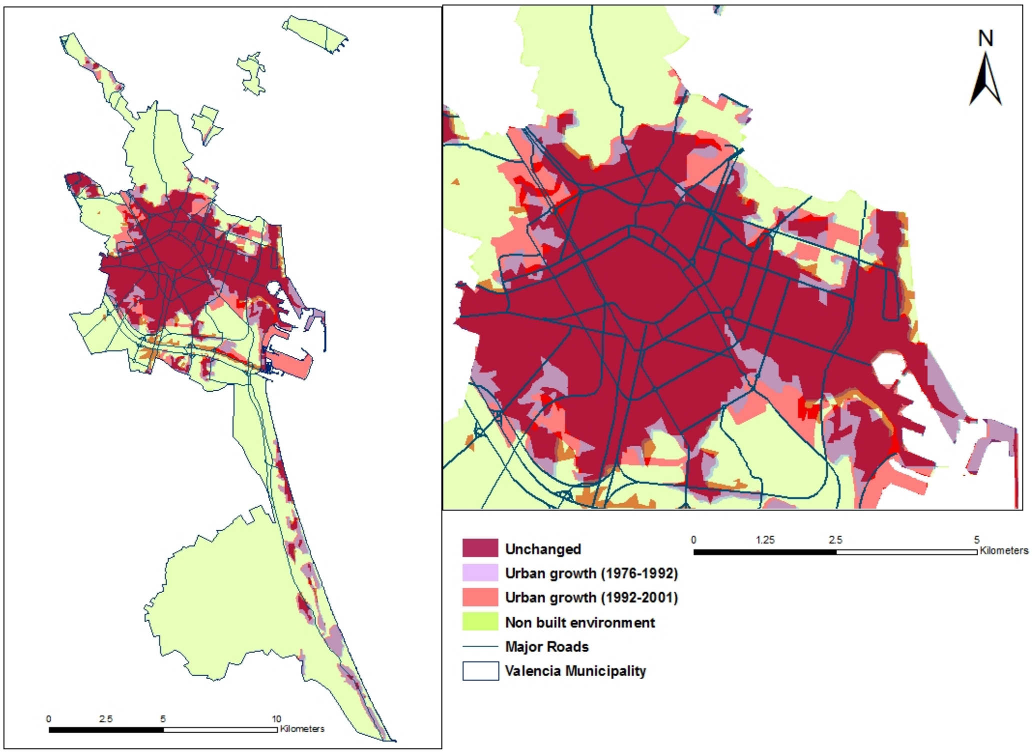

Fig. 8(b). Municipality map showing high ways and the urban growth from 1976 to 2001

The relationship between population growth and growth in urban-built up surfaces as determined from the Landsat derived change maps was also examined (Fig. 9). Despite the date difference in the census years and the land cover mapping, the pattern of urban expansion and the population growth showed a consistent and distinct pattern with urban space especially with the recent urban expansion from 1992- 2001. Hence, the pattern of urban growth and expansion reflected the distribution of population. However, the pattern of urban expansion and the population growth did not show a consistent and distinct pattern within some districts of the urban space. The reason might be the construction of multi-story buildings in the already urban core zone that can accommodate the growing population. Hence, a clear diagnosis would allow seeing as to how population variable explain the pattern of urban growth in the region.

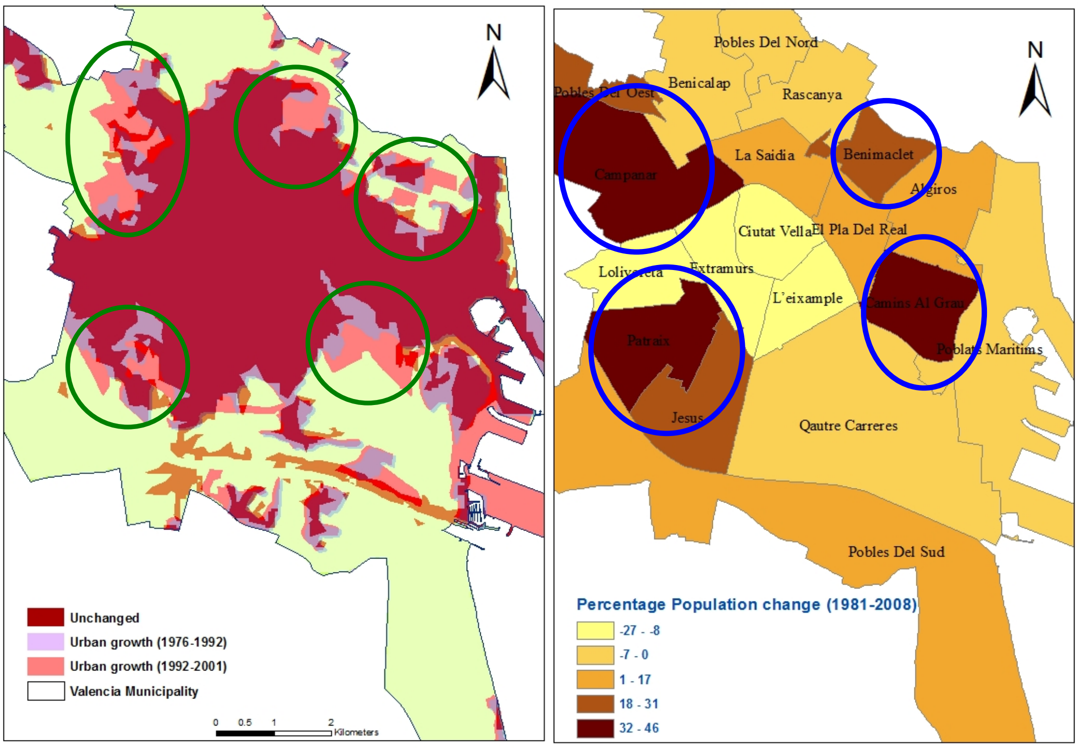

Fig. 9. Pattern of Land use change and percentage population change in Valencia Municipality

4.4 Spatial Transition of Land Use/Land Cover Change Analysis using Spatial Metrics

The spatial dynamics of land cover refers to the temporal change in the size, number, shape, adjacency and the proximity of patches in a landscape. A change in urban land cover changes can be well described using information from spatial metrics. A set of spatial metrics can be used in a detailed analysis of growth patterns mapped from the remote sensing data and extended to interpret and analyze the change in spatial structure of urban growth (Herold, et al., 2003). Spatial metrics have to be selected, interpreted, analyzed and evaluated according to the context of the study, given the thematic classification and the inherent processes of change (Gustason, 1998).

In this study the calculation of the spatial metrics was based on the classified thematic maps representing a landscape consisting of spatial patches categorized in different patch classes. The metric calculations were performed using FRAGSATAS version 3.3 (McGarigal, et al., 2002).

Once the initial classifications have been performed, additional information and pattern analysis could be developed. A small set of landscape metrics were used to explore changes in both the compositional and structural aspects of landscape pattern in the municipality (Table 9). Analysis of the landscape pattern were conducted at the class levels both with the six classes land cover maps and the reclassified built and non-built maps. For each class, total class area, mean patch size, number of patches, percentage of landscape, largest patch index, and area-weighted fractal dimension index were calculated (Table 10a and 10b).

Table 9. Spatial metrics used for this study (after McGarigal et al, 2002)

Class Metrics	Abbreviation	Descriptions
Total Area/Class Area	CA/TA	CA measures total areas of classes (built and non built) areas in the landscape.
Number of Patches	NP	NP is the total number of patches in the landscape.
Mean Patch Size	MPS	MPS is the average area of (m2) of all patch in the landscape (unit: ha).
Percentage of Landscape	PLAND	PLAND equals the percentage of the landscape comprising the corresponding patch type.
Largest Patch Index	LPI	LPI percentage of the landscape comprised by the largest patch.
Area Weighted Mean Patch Fractal Dimension	FRAC_AM	Area weighted mean value of the fractal dimension values of all urban patches, the fractal dimension of a patch equals two times the logarithm of patch area (m2), the perimeter is adjusted to correct for the raster bias in perimeter.

Analysis of the spatial metrics CA/TA indicated that the urban land cover has increased approximately from 3415.8 (24.7%) to 4699 ha (34.1%) from 1976 to 2001. Agriculture decreased from 6559.8ha (47.6%) to 5493.2 (39.9%), wetlands from 3.1% to 2.7%, barren from 1.7% to 1.5%, and water 19.6 to 18.5 %. Forest cover class showed insignificant cumulative change in the mentioned periods (Table 10a). The result of the growth and reduction is assumed to be affected by the season of image acquisition and classification. The result also showed a decrease in the number of patches (NP) from the urban-built up class reflecting that many fragmented built up patches were integrated to the existing neighboring built up areas (i.e. Contagion of neighboring built up areas).

Similarly, the number of urban-built up patches decreased from 41 in 1976, to 29 in 1992 and to 26 in 2001 sequentially. This indicated the growth of individual development core together and aggregation of spatially closer built up surfaces within the metropolitan. The largest patch index (LPI) has changed between 1976 and 1992 and the change was lower for built up areas i.e. from 21.1% to 22.5%, however, this value increased from to 27.7% in 2001. Over time, with the dramatic increase of urban built up areas in the successive years of 1992 to 2001, the value of LPI was increasing. Hence, the LPI metric showed the evidence of large urban growth in the region. This increasing of largest patch index further confirmed the spatial growth of urban areas around an existing urban core with less fragmentation of urban fabrics and other artificial surfaces.

The results supported by the declining number of patches, PLAND and LPI revealed the pattern of built up surface change was at the expense of other non-built up classes, in particular, the larger agricultural patches which once comprised the largest land cover composition in terms of percentage of landscape (PLAND) and class area (CA) (Table 10a). Most of the increase in urban development has occurred next to the existing metropolitan area with less fragmentation and suburbs within the municipality.

Table 10(a). Change in Landscape pattern in Valencia Municipality using spatial metrics (1976-2001)

Land cover type	Class area (**CA/TA**) (ha)			Number of patches (**NP**) (#)			Mean patch size (**MPS**) (ha)			Percentage of Landscape-PLAND (%)			Largest patch Index (**LPI)** (%)			Area-weighted Fractal Dimension Index **FRAC_AM**		
	1976	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**
Built up	3415.8	4042.3	4699.0	41	29	26	83.0	139.5	180.7	24.7	29.4	34.1	21.1	22.5	27.7	1.2	1.1	1.1
Agriculture	6559.8	6048.4	5493.2	28	18	9	234.2	335.7	274.8	47.6	43.8	39.9	15.5	10.2	9.2	1.5	1.2	1.2
Forest	474.5	435.8	461.9	4	3	3	117.5	145.2	153.9	3.4	3.1	3.4	2.9	1.7	1.8	1.2	1.2	1.2
Barren	235.7	220.3	205.5	18	18	19	13.2	12.6	11.4	1.7	1.6	1.5	0.5	0.4	0.6	1.1	1.1	1.2
Wetland	434.4	370.5	353.8	21	8	9	20.4	45.9	40.7	3.1	2.7	2.7	1.2	0.7	0.6	1.2	1.2	1.2
Water	2695	2690.8	2584.7	13	22	29	206.1	64.1	27.8	19.6	19.5	18.5	16.4	16.9	19.9	1.1	1.1	1.1

Table 10(b). Change in Landscape pattern of built up- non-built up surfaces in Valencia Municipality using spatial metrics (1976-2001)

Land cover type	Class area (**CA/TA**) (ha)			Number of patches (**NP**) (#)			Mean patch size (**MPS**) (ha)			Percentage of Landscape **PLAND** (%)			Largest patch Index (**LPI**) (%)			Area-weighted Fractal Dimension Index **FRAC_AM**		
	1976	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**	**1976**	**1992**	**2001**
Built up	3415.8	4042.3	4699.0	41	29	27	83.0	139.5	180.7	24.7	29.4	34.1	21.1	22.5	27.7	1.2	1.1	1.1
Non-built	10369.9	9760.7	9092.3	21	42	56	493.8	232.4	162.4	75.3	70.6	65.9	55.8	52.5	49.7	1.1	1.2	1.2

On the other hand, CA, NP, LPI for agriculture has shown a remarkable decrease (Table 10a). This clearly indicated that the prevalence of change in the compositional aspect of landscape pattern. After the 1992, the change in most of these non built land cover classes including agriculture, barren, wetlands and water has shown dramatic changes considering the spatial metrics parameters of CA, NP, MPS and LPI. As can be seen from Table 10(a), the spatial metrics value for these land cover classes decreased substantially and this showed the prevalence and relative increment of landscape fragmentation and structural changes within the municipality. Relatively speaking, the structural and compositional structure for forest class has been constant. This might indicate there was a consistent protection of forest resources following many environmental management agreements and initiatives.

The fractal dimension describes the complexity and the fragmentation of a patch by a perimeter-area proportion. Fractal dimension values range between 1 and 2 (McGarigal et al., 2002). Low values are derived when patches have a compact rectangular form with a relatively small perimeter relative to the area. If the patches are more complex and fragmented, the perimeter increases and yields a higher fractal dimension. The fractal dimension can be applied as a derived metric called Area Weighted Mean Patch Fractal Dimension (FRAC_AM). FRAC_AM averages the fractal dimensions of all patches by weighting larger land cover patches. This improves the measure of class patch fragmentation because the structure of small patches is often determined more by image pixel size than by characteristics of natural or manmade features found in the landscape (Milne, 1991)

The area weighted mean patch fractal dimensions of built areas was small (1.1) and the metric value remain almost unchanged during the recent two periods of study (Table 10a & b). This lower value implied the less complexity and absence of fragmentation of urban patches in the study periods. This assertion could be mapped from the visual comparison of the change detection map (Fig. 8a).

The lower and constant patch fractal dimension and declining NP indicate that there was a continued growth in the region from the already central urban core and implied a connection of the formerly diffused and fragmented urban areas within the municipality to the metropolitan core region. In other words, the lower FRAC_AM dimension result indicated the absence of rapid urban sprawl and leap-frog style urban development with less fragmentation of new developments and increasing compactness of urban built up surfaces. In brief, the spatio-temporal pattern of urban development using spatial metrics showed the existence of rapid urban growth adjacent to the historical urban core with less fragmentation and lower rate of sprawl. The spatial complexity has declined as most of the urban built up surfaces expand following the existing urban boundary with little sign of fragmentations following the increasing development pressure economic growth and tourism economies in the region. The growing expansion of urban fabrics would put immense environmental impacts through soil desiccation and consumption of fertile agricultural plots.

On the other hand, the “Plan General de Ordenación Urbana” (General Urban Plan) of Valencia municipality was approved around 1988 (Fig.10). The land type for management map is a map which showed (apart from the existing urban areas) the planned land and its use for future. Among others, one category is land planned to be urban (or industrial, etc.). In the case of artificial surfaces, this planned new use would be done at the expenses of existing agriculture land or even natural surfaces if they are not protected as such in land type for management map.

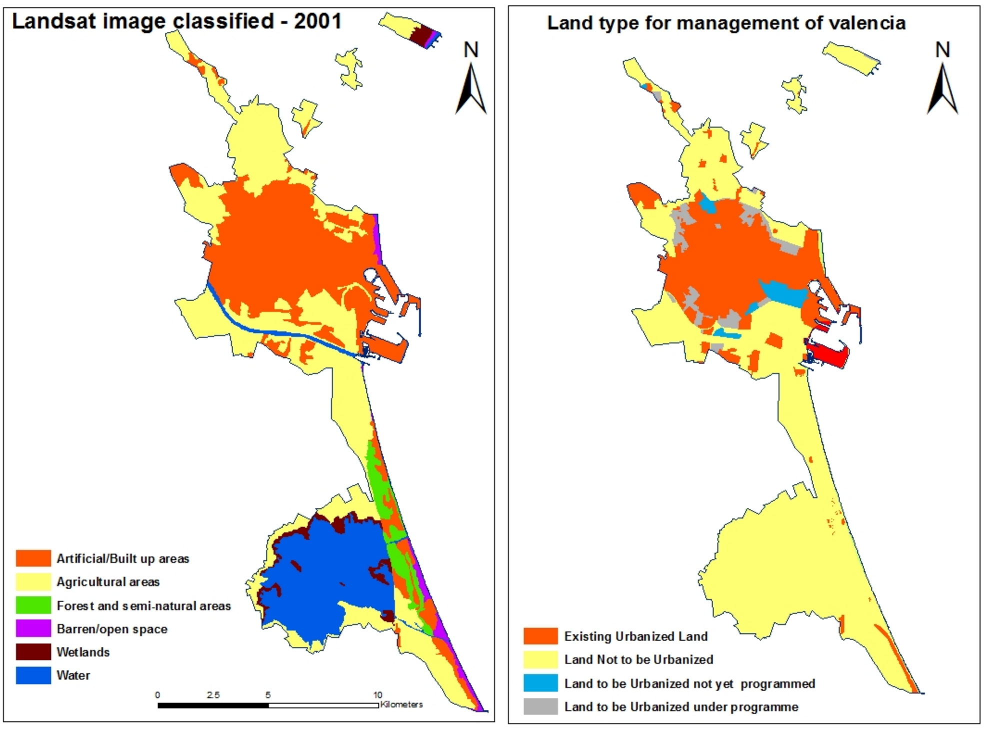

Fig. 10. Comparison of Land use/land cover (2001) and Land Type for Management Map (1988)

Looking the above mentioned discussions and the visual comparison of our land cover classification and the Municipality Land Type for Management map, the urban growth in the Valencia Municipality was constrained by planning and management efforts and resulted in a less fragmented and more compact urban area. Disagreements between our 2001 land use-cover map and the land type for management map would be related to: (a) accuracy of the satellite image resolution and classification method and (b) real urban growth that was not originally planned, but legal modifications were introduced with time. Similarly, disagreement between both maps in the northern area of existing urbanized land would have to be understood as remote sensing misrepresentation and generalization from the classifier side. Despite this, as can be seen from the map (Fig. 10) land to be urbanized not yet programmed and land to be urbanized under programme were adjacent to the existing urban land. Hence, this implied the existence of a compact growth and less fragmentation. However, with the given rapid rate of growth, there is a high probability/tendency to convert the protected areas under the current management plan. Hence a remedy has to be designed incorporating dynamic studies from the GIS and remote sensing disciplines. This would be useful for sustainable city growth that protects the surrounding fertile agricultural plots and other resources including soil and water in the Mediterranean region.

4.5 Temporal Patterns of Land Use/Land Cover Changes

Land use/land cover classifications and relative changes from 1976 to 2001 in the Valencia municipality are depicted in Fig.6 and 7. Furthermore, in a close look at (Figure 8(b) 9 and 10,) spatial patterns of land cover revealed that urban built up surface expansion/growth followed certain directions depending on the new plan for land type for management, developing highways and relatively population growth . Built-up areas showed dramatic increase while other non built-up surfaces substantially decreased from 1976 to 2001. Expansion of built up surfaces has exhibited a consistent response since 1976 to 2001 in its areal extent (Fig. 11). There had been a continuous conversion of non-built up surface to built-up environments especially in areas adjacent to the existing urban boundaries in temporal dynamics.

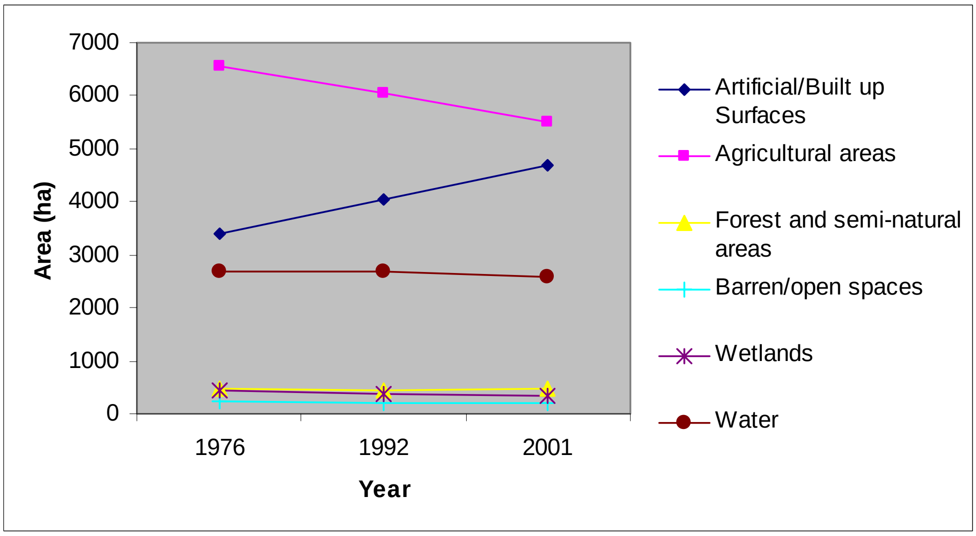

Fig. 11. Temporal patterns of land use/land cover changes (1976-2001)

The recent 2001 year image classification indicated that there had been a rapid land cover change from agriculture to urban-built up and other artificial surfaces. This expansion has been visible in everywhere from the already existing built up surface and in the direction of the port. Currently, the tremendous urban growth and expansion was consuming the fertile agricultural fields adjacent to the city boundaries.

The temporal nature of land use/land cover changes revealed that the built up surfaces had been increasing significantly (Table 8). For instance, in the 1976 built up areas were 3415ha which increased gradually to 4042 ha in 1992, indicating 18 % growth within 16 years intervals. Seemingly, the built up surface increased to much higher from 4042ha to 4699ha between 1992 and 2001 representing a higher extent of change 16 % within 9 years difference. Figure 11 portrayed the temporal change of trends of land use/land cover change during 1976-2001. This figure signified the dramatic land cover change on the category of built up surface exerting an incredible pressure on non-built up surfaces, in particular agricultural lands.

Furthermore, concerning temporal changes, results of the investigation of spatial metrics revealed that changes in landscape structures were common. There have been changes in the class area, number of patches, mean patch size, percentage of landscape, largest patch index, and area weighted fractal dimension index over time. Hence, careful application of spatial metrics could be useful to interpret land use/land cover dynamics with time series data of such type. However, monitoring changes require a high quality standard of geographic data with temporal consistency in order to avoid any data related distortion of the results.

In conclusion, based on these empirical results the city could be categorized as one of the fastest growing city in the Spanish and European context in spatial and temporal terms. As a result, an integrated assessment of land use/land cover change mapping and spatial and temporal modeling works should be done. The task has to integrate remote sensing, spatial metric tools and socio-economic data to manage urban growth and expanding impervious surfaces. It will foster environmental management of soils and water that were/are continuously affected by urban growth and growing impervious surfaces and the associated, water pollution and stress, soil desiccation and degradation in the region.

4.6 Limitations of the Research

Despite the fair proceeding and accomplishment of the research, a number of challenges were encountered in the process. To mention some of them:

i. Lack of consistent multitemporal Landsat satellite data from the same season that would have allowed comparison of images and perform change analysis. Furthermore, lack of images from different season of the same year for identifying features from image reflectance value.

ii. Limited access to different digital orthophotos with full coverage of the municipality from various years to collect training sample from the study area created limitation on visual interpretation and the classification process.

iii. The inconsistency of the geo-reference of Landsat images and the local datum and data formats of different layer files were time taking to get consistent data.

iv. The lack of consistent socio-economic data, very recent Landsat image and high resolution imageries like IKONOS, QuickBird and other ancillary data hindered calibrating a land use model within the municipality.

5. CONCLUSIONS

This study has shown that information from satellite remote sensing and integrated with GIS can play a useful role in understanding the nature and extent of changes in land use/ land cover, where they are occurring and monitoring these changes at local scale. The change detection analysis integrated with spatial metrics performed in this research allowed for the monitoring of land use/ land cover changes overtime and space. The analyses provide valuable insight into the extent and nature of changes that has taken place in the Valencia municipality from 1976 to 2001 and lays foundation for further research to be conducted that aims modeling and prediction of future changes.

The dynamics of land use/land cover change pattern have been identified by analyzing the multi-temporal satellite images of 1976, 1992 and 2001 in a GIS platform. The quantitative evidences of land use dynamics revealed the dynamic growth of artificial surface. Conversions of land from agriculture to urban land represent the most prominent land cover change. The rate of change was as high as 1.8 % for built up surface while agricultural lands were converted at 1% per year. The trend and extent of urban change is likely to continue with the rapid development of infrastructure, tourism economy and increasing of population. The majority of changes in urban built up surface occurred in most direction of the city; however, in the recent times, the intensity was higher at the north-west, north-east and south and south-west of the metropolitan area of Valencia following increasing development pressure.

The spatial metric calculations e.g., class area, number of patch, largest patch index, mean path size, and patch fractal dimension values revealed that, there was a continued growth in the built up surface. Rapid urban growth has been contiguous to the historical urban core with less fragmentation. Built up surface expansion followed certain pattern depending on the increasing development pressure and highways. Conversely, spatial metrics value for the non-built up classes decreased substantially over time showing relative increment of landscape fragmentations. Evidences from spatial metrics values indicated the absence of rapid urban sprawl and leap-frog style urban development and less fragmentation with increasing compactness of urban built surfaces. In general, the analyses illustrated the potential of Landsat data and spatial metrics to capture the structural and compositional properties of landscape at the municipality level in Valencia. Further, it allowed determining and monitoring land use dynamics and the evolution of urban agglomerations in the region. Furthermore, the visual comparison of land cover maps and the Municipality Land Type for Management map revealed that urban growth in the Valencia Municipality was constrained by planning and management efforts and resulted in a less fragmented and more compact urban area. However, with the given rapid rate of growth, there is a high probability to convert the protected areas under the current management plan.

In order to alleviate the dramatic land use/ land cover change and adverse environmental impacts of urban expansion and increasing built up surfaces, the current growth pattern needs to be managed through effective land use planning and management. This would be useful to protect the fertile agricultural land in the region and further reduce environmental degradation in the form of soil erosion and desiccation and water stress and pollution.

Future research works should focus on integrating GIS and satellite remote sensing with high spectral, spatial and temporal resolution at the local scale to develop urban environmental monitoring. The application of new generation QuickBird and IKONOS satellites having high spectral and spatial resolution will allow achieving high accuracy in classification and mapping in the municipality. However, the greater spatial detail has to be carefully handled in the geospatial analysis. Image classification algorithms from object oriented and fuzzy object should be applied to avoid the common mixed pixel problems in pixel based image classification. Moreover, research works should draw attention to urban land use modeling and techniques integrating socio-economic data and GIS tools to predicting future pattern of change. Focus should be given to the effect of urban growth and growing impervious surfaces and the associated, water pollution and stress, soil desiccation and degradation and the likely impacts on the Mediterranean fragile environments and resources. The region should pursue social and economic development alongside with protection of the environment and natural recourses to achieve sustainable development as mentioned at Agenda 21 of Rio Declarations.

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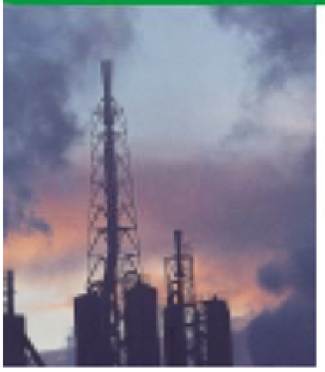
APPENDICES

Appendix 1. Descriptions of CORINE Land Cover nomenclature

1. Artificial surfaces

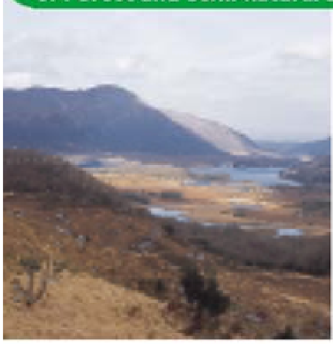


1.1. Urban fabric	1.1.1. Continuous urban fabric
	1.1.2. Discontinuous urban fabric
1.2. Industrial, commercial and transport units	1.2.1. Industrial or commercial units
	1.2.2. Road and rail networks and associated land
	1.2.3. Port areas
	1.2.4. Airports
1.3. Mine, dump and construction sites	1.3.1. Mineral extraction sites
	1.3.2. Dump sites
	1.3.3. Construction sites
1.4. Artificial, non agricultural vegetated areas	1.4.1. Green urban areas
	1.4.2. Port and leisure facilities

2. Agricultural areas

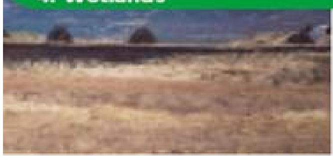
2.1. Arable land	2.1.1. Non-irrigated arable land
	2.1.2. Permanently irrigated land
	2.1.3. Rice fields
2.2. Permanent crops	2.2.1. Vineyards
	2.2.2. Fruit trees and berry plantations
	2.2.3. Olive grives
2.3. Pastures	2.3.1. Pastures
2.4. Heterogeneous agricultural areas	2.4.1. Annual crops associated with permanent crops
	2.4.2. Complex cultivation patterns
	2.4.3. Land principally occupied by agriculture, with significant areas of natural vegetation
	2.4.4. Agro-forestry areas

3. Forest and semi-natural areas



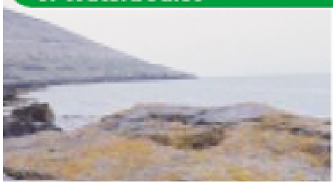
3.1. Forests	3.1.1. Broad-leaved forest
	3.1.2. Coniferous forest
	3.1.3. Mixed forest
3.2. Scrub and/or herbaceous vegetation associations.	3.2.1. Natural grasslands
	3.2.2. Moors and heathland
	3.2.3. Sclerophyllous vegetation
	3.2.4. Transitional woodland-scrub
3.3. Open spaces with little or no vegetation	3.3.1. Beaches, dunes, sands
	3.3.2. Bare rocks
	3.3.3 Sparsely vegetated areas
	3.3.4. Burnt areas
	3.3.5 Glaciers and perpetual snow

4. Wetlands



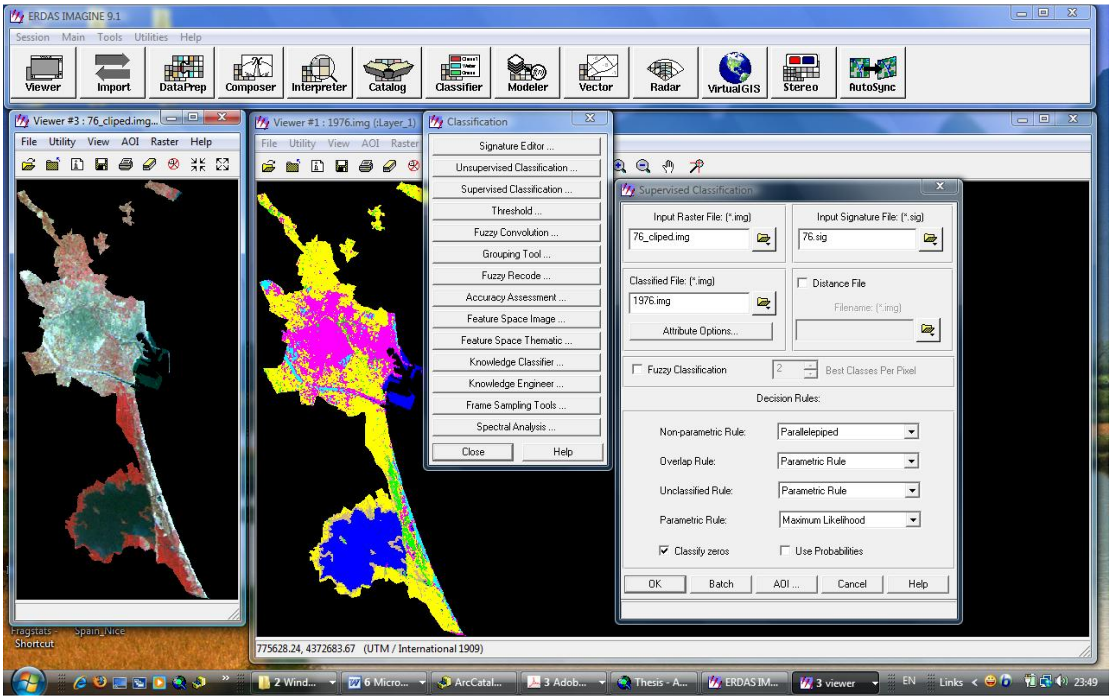
4.1. Inland wetlands	4.1.1. Inland marshes
	4.1.2. Peat bogs
4.2. Maritime wetlands	4.2.1. Salt marshes
	4.2.2. Salines
	4.2.3. Intertidal flats

5. Waterbodies

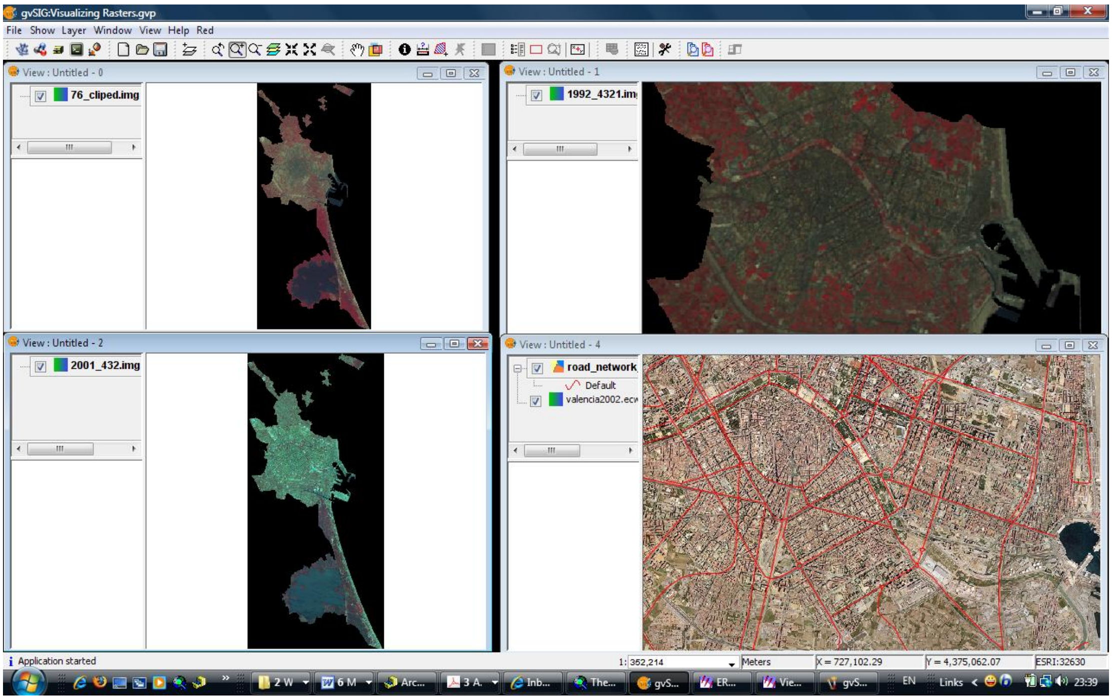


5.1. Inland waters	5.1.1. Water courses
	5.1.2. Water bodies
5.2. Marine waters	5.2.1. Coastal lagoons
	5.2.2. Estuaries
	5.2.3. Sea and ocean

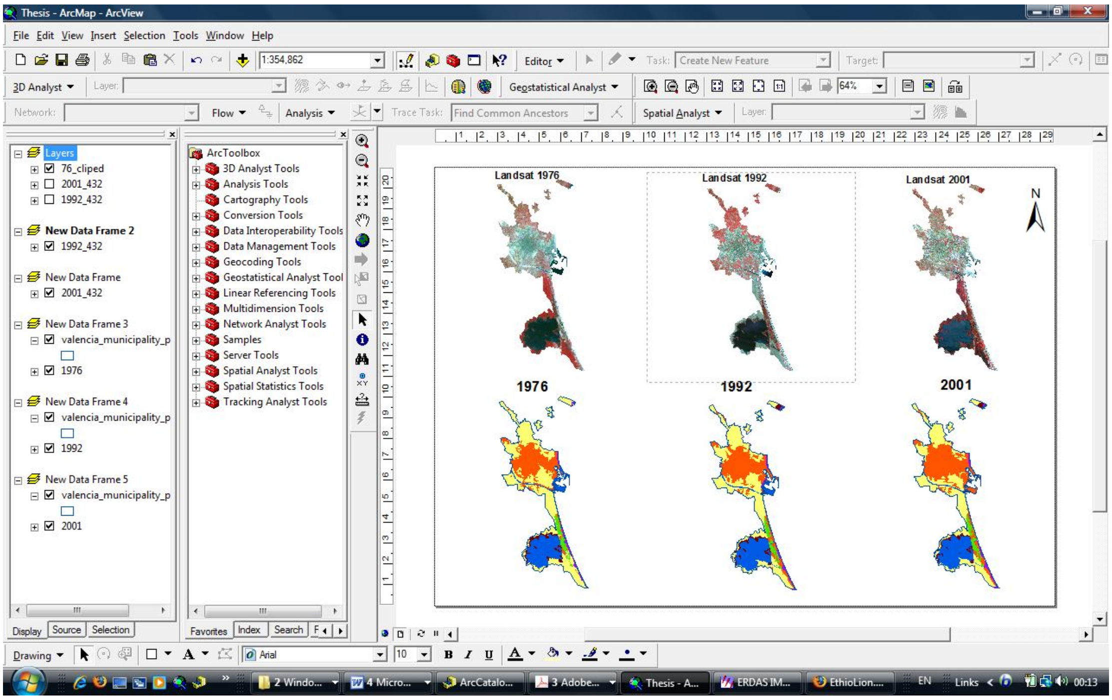
Appendix 2. Screenshots of tools/software used in the study



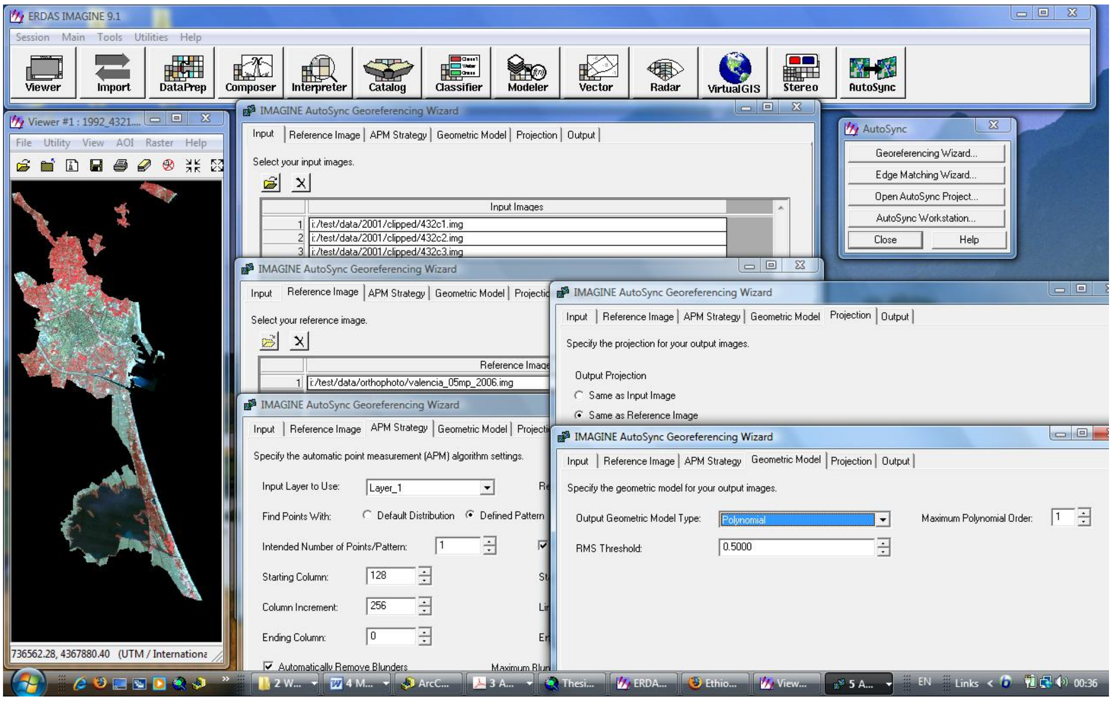
a. ERDAS Imagine 9.1 for image classification



b. gvSIG for visualizing raster (http://www.gvsig.gva.es/)



c. ArcGIS 9.2 for visualizing and manipulating layers and images



d. Landsat image Georeferencing

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Addis Getnet Yesserie

Dissertation submitted in partial fulfilment of the requirements for the Degree of *Master of Science in Geospatial Technologies*

Universidade Nova de Lisboa
Universitat Jaume I
Westfälische Wilhelms-Universität Münster

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