Using Geographical Information Systems in the environmental assessment of urban environments: the Elainonas area in Attica, Greece

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ABSTRACT: Much attention has been given to land-use, urban environment and its associated development. Such development aims to find methods for assessing and evaluating its environmental impact that will consequently enable the concept of sustainability to expand. Effective planning and management requires data on current conditions and an ability to foresee the likely consequences of proposed projects and policies. The aim of this article is to demonstrate the multiple use and choices of the advanced techniques and methods of the digital processing of satellite data and of the Geographical Information Systems (GIS) in the environmental assessment of the urban environment. It creates an integrated and multi-dimensional methodology for the appropriate monitoring of environmental parameters and phenomena. The ultimate purpose is the formation of managerial action plans and the scheduling of projects in environmentally polluted areas, assisting in the overall concept of the sustainable city. The research uses the area of Elaionas in Attica, Greece, as a case study.

INTRODUCTION

Much attention has been given to land-use, urban environment and its associated development. Such development aims to find methods for assessing and evaluating its environmental impact that will consequently enable the concept of sustainability to expand. Cities worldwide are faced with the challenge of achieving sustainable development in the overall context of poverty reduction and good urban governance.

Effective planning and management requires both data on current conditions and an ability to foresee the likely consequences of proposed projects and policies. The increasing rate at which the built and natural environment changes has caused a lot of concern for urban and regional planners. Therefore, they have had a particular interest in estimating future impacts on land-use development of existing spatial plans and policies, and considering alternative planning and policy scenarios for impact minimisation.

The Environmental Impact Assessment (EIA) process comprises several stages, including screening; scoping; identification of potential impacts; prediction of impact magnitudes; evaluation of impact significance; public consultation; development of mitigation options; comparison of alternatives and decision-making. The decisions may relate to requiring the developer to provide mitigation, to consider alternative sites or routes or simply not to proceed. There are numerous existing methodologies that attempt to facilitate EIA and these include index and matrix methods, ecological assessment and networks, quantitative methods and overlays [1][2].

In urban planning, the design of policies for sustainable development poses the problem of dealing with systems in which natural and human factors are interrelated. Understanding the processes that cause these systems to change and knowing their spatial implications is essential in preparing effective policies. In order to help policy makers see through this complexity, spatial data that aim to represent reality as realistically as possible are required [3]. Accurate mapping of land-use in order to monitor and audit the parameters of change within time and space has been identified as a need of major significance.

Geographical Information Systems (GIS) are computer software tools that enable spatial data to be stored, analysed, modelled and presented, and have a significant role to play in environmental modelling and EIA [4][5]. Remote sensing provides the means for observing earth features and phenomena with valuable spatial, spectral and temporal accuracy. Such technologies can assist in a better understanding of the different patterns and linkages of the physical and, possibly, the social environment. The use of GIS and remote sensing in the assessment of environmental sensitivity to development has been successfully demonstrated in different fields and disciplines, as is further illustrated below.

APPLICATION OF GIS AND REMOTE SENSING

One of the main difficulties that arise during the EIA process is the generation and management of data concerning environmental conditions and predicting the potential impacts, which might arise from a project/development. The earth's climate, natural hazards, population, geology, vegetation, soils, land use and other characteristics can be analysed in a GIS using computerised maps, aerial photographs, satellite images, databases and graphs. Considering that environmental characteristics such as land-use vary spatially, the value of GIS and remote sensing as a tool for environmental modelling and decision-making has been widely acknowledged. For example, Haines-Young et al discussed the use of GIS for landscape ecology [6] and Canter referred to GIS as a tool for land-use and soil impact evaluation [7]. In Longley et al [4] and Goodchild [8], the role of GIS in environmental modelling was illustrated. Hunsaker et al discussed methods and techniques to integrate spatial ecological models with GIS [9].

Many authors have discussed the value of GIS as a tool specifically for EIA (e.g. [1][2][7][10][11]). Glasson et al suggested using GIS in EIA as a means of speeding up and improving the process of collecting and storing data [2]. Sankoh et al employed GIS to create maps indicating the relative value of protecting different regions within a specific area in order to compare alternative routes [12]. Eade and Moran adopted a spatial approach using GIS for the economic evaluation of the environment using the Rio Bravo Conservation and Management Area as a case study [13]. Canter [7] and Glasson [14] proposed using GIS to compare and select between alternatives and identify optimum corridors for developments such as roads. Haklay et al explored the potential of using GIS as a basis specifically for the scoping stage of the EIA process [15].

Reginster and Goffette-Nagot used GIS functions together with aerial photographs, satellite images and ancillary data to construct spatial representations to evaluate the impact of environmental quality on land rents [16]. Nickol and Wong demonstrated the ability of satellite-based sensing systems to depict parameters of urban environmental quality over large areas at detailed level, using 3D Virtual Reality models to obtain a more accurate representation of the urban environment [17]. The models permit 3D visualisation and fly-through animation to represent urban environmental quality, based on quantifiable image parameters, and assist in making the complex and dynamic factors controlling urban environmental quality more understandable.

Recognising the need for spatial information, the European Union created a legal framework for the establishment and operation of an Infrastructure for Spatial Information in Europe for the purpose of formulating, implementing, monitoring and evaluating Community policies at all levels and providing public information. According to the European Union, a good policy depends on high-quality information and informed public participation [18]. The Sixth Environment Action Programme emphasises that environment policy needs to be based on sound knowledge and informed participation. It is argued that spatial information can play a special role in this new approach because it allows information to be integrated from a variety of disciplines for a variety of uses.

According to the European Environment Agency, throughout the world and in particular in Europe, processes related to urbanisation, development of transport infrastructures, industrial constructions and other built-up areas are influencing the environment severely, and often modify the landscape in an unsustainable way [19]. In this respect the MOLAND project (Monitoring Land Cover/Use Dynamics), which is coordinated by the Institute for Environment and Sustainability of the European Commission's Joint Research Centre, aims to provide up-to-date, standardised, comparable information on the past, current and likely future land use development in Europe [20]. As part of MOLAND, an urban growth model that is used to assess the likely impact of current spatial planning and policies on future land use development has been developed. The aim of MOLAND is to assess, monitor and model past, present and future urban and regional development from the viewpoint of sustainable development by setting up land use and transport network databases for various cities and regions in Europe.

The above discussion illustrates that there is a role for spatial-related technologies in the EIA and decision-making process for urban environments.

THE METHODOLOGY

An integrated and multi dimensional methodology for the appropriate monitoring of environmental parameters and phenomena, with an ultimate purpose for the formation of managerial action plans and scheduling of projects in environmentally polluted areas assisting in the overall concept of sustainability and sustainable city is described and discussed in this article. In addition, the authors describe how this methodology has been applied to a real case study.

The methodology developed demonstrates the multiple use and choices of the advanced techniques and methods of the digital processing of satellite data and of GIS in the environmental assessment of the urban environment and in particular of building projects. This approach is based on the hypothesis that very high spatial resolution data can be used to produce very high resolution map products such as urban thematic maps, thus discriminating and mapping the urban complexes with considerable accuracy of (± 2 metres). By extracting the different types and the various urban land-use features, it is possible to assess the environmental impact to/from an urban building, using also other parameters such as ancillary map data, measurements of pollution distribution and meteorological data in a GIS system [21].

For the purpose of this study, several images were tested such as Landsat ETM (15-metres), IRS-1C (5-metres) and the most important was the IKONOS-2 data set acquired in June 2003. These data sets were geometrically corrected using more than 40 Ground Control Points (GCP) and 20m digital elevation model (DEM). The root mean square error of the GCPs was less than 0.8 pixels, while the same error at the checkpoints was less than 1 pixel. This shows that in areas where elevation changes are not large, the necessity for large-scale DEMs is diminished. It was also demonstrated that users can process IKONOS GEO data to the same standards of accuracy available from the Precision IKONOS data all at a lower cost and in less time.

THE CASE STUDY

The proposed methodology was applied to a real case study, the area of Elaionas in Attica, Greece (Figure 1). The implementation of the methodology in a real case study produces a useful database upon which possible scenarios of urban development with protection of the environment being provided at the same time. The specific area, Elaionas, is an industrial area in the middle of Athens, the capital of Greece. It captures the central part of the wider Athens area and it is the last area that does not follow town planning guidelines. Approximately 9,000,000 m^2 of land close to the centre of Athens and the archaeological sites were converted gradually after World War II from agricultural land to industrial use with no planning and no infrastructure. Elaionas is a heavily polluted area and its contribution to the capital's wider pollution problem is large. In the Elaionas area, the development of a new building (football stadium and shopping facilities) was proposed and its impact in such a polluted area assessed.

Figure 1: Overview of the Elaionas area.

The Application of the Case Study

Detecting urban features from high-resolution remote sensing data such as IKONOS and QUICKBIRD might become one of the most challenging tasks of remote sensing within the coming years [22]. In many cases, this can only be obtained through the analysis of remote sensing data. The IKONOS-2 satellite launched in September 1999 by Space Imaging Inc. is the world's first commercial satellite offering high spatial resolution imagery. The IKONOS sensor suite is capable of generating 1m panchromatic images with off-nadir viewing up to 60° in any azimuth for a frequent revisit rate and stereo capabilities. The satellite can provide one-meter resolution, near-real time information that will offer numerous benefits in urban planning. This makes it possible, in principal, to perform operational tasks within urban areas varying from simple mapping to change detection. Thereby gaining useful information from the image data is the most crucial task. As pixels alone do not hold enough information to detect the different phenomena, advanced and mostly knowledge-based methods seem to be more adequate [23].

Furthermore, a question arises regarding the extent to which the existing image processing software packages and algorithms can fully extract and exploit the rich information content of the high-resolution images and their image clarity and sharpness in order to integrate them in the decision-making processes for urban planning purposes. Classification algorithms can automatically detect and discriminate between similarities and unevenness of various urban land-use types and register differences inside a plot caused by variation of the mixed and multiple land-use status [24]. Furthermore, twenty eight classes were selected and processed on IKONOS-2 data. These included the AMSTEL Brewery, Athens Central Vegetable Market, Athens paper mill (SOFTEX), Athens Urban Transport Bus Garage, Athletic Facilities, Cart Speedway, Court Martial, DELTA factory, Disused Areas, Drivers Training Cultural Centre, EVGA Factory, Foundation of the Hellenic World, Industrial Buildings/Facilities, Industrial Open Spaces, Kifisos Central Bus Station, MAKRO Mall, Navy History Service, OTE Supply Depot, Parks, Public Hydrophobia Clinic, Recreational Parks, Rouf Military Facilities, Schools, University campus, Homogeneous Urban areas, Vegetated Areas, Village Park, and the Road Network (Figure 2).

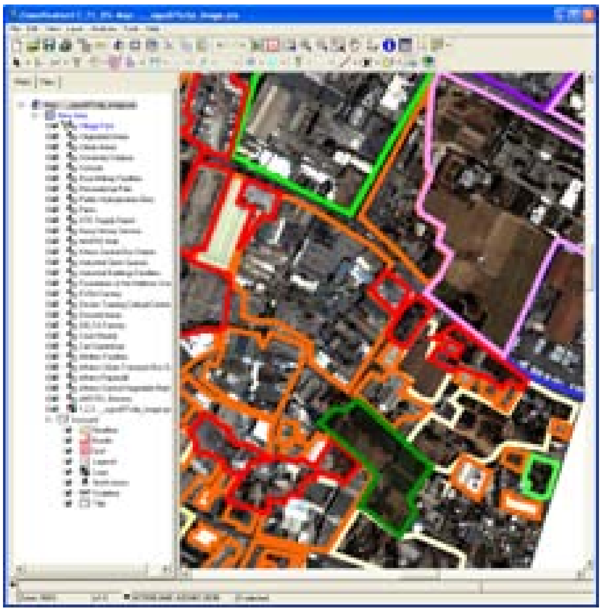

Figure 2: Highlights of the classification polygon outlines.

All imagery-derived land-use and land-cover class-polygons feed to a GIS system together with other ancillary map-based information (transportation infrastructure, town planning drawings, location of air pollution detectors, etc) and meteorological data measurements distribution such wind, temperature, humidity and concentration of NO, NO_2, CO, CO_2 and O_2. The GIS provides an integrated computational environment of heterogeneous data, together with incompatible data from other sources (such as digital maps, raster, vector, tabulated data, coastlines, municipality borders, districts, etc). This allows the problems, which have not yet been resolved with concurrent interface and full exploitation of the available information to be resolved for usage in any environment planning and development and for support of political decision at multiple levels (urban, town planning, sustainable development, environmental, etc).

The use of remotely sensed data is encouraged by the fact that such data can offer detailed information about the inventorying of the land-use and land-cover and urban land-use change in time to users. The high spatial resolution multi-spectral satellite data in pan-sharpened mode through methods of rendering and digital analysis allowed the area determination of the urban land-use and its subtle changes that are sometimes occurred in areas that are smaller than 100 sq. metres. These data assisted in extracting the parameters to be evaluated and allowed them to be measured quantitatively (spatial analysis) and qualitatively (classification, type) through an integrated GIS system so that they provide criteria for the evaluation of urban building work.

Data Sets and Tools

In this study an IKONOS-2 data set (pan-sharpened all four bands) was procured together with Landsat ETM data and IRC-1C images (July 2003). Moreover, general land-use topo maps (1/25,000) were acquired from the Hellenic Army Geographical Service (HAGS) and geological maps of the same scale from the Institute of Geology and Mineral Exploration (IGME), Athens. Town planning drawings (1/2,000, 1/5,000) and revised plans were provided by the Organisation of Athens.

The revised town planning proposals, including the construction of a new football stadium, revealed the environmental, socioeconomic and ecological impact in the surrounding area when overlaid onto the high resolution image and interrelated with other vector based information through the GIS system (Figure 3).

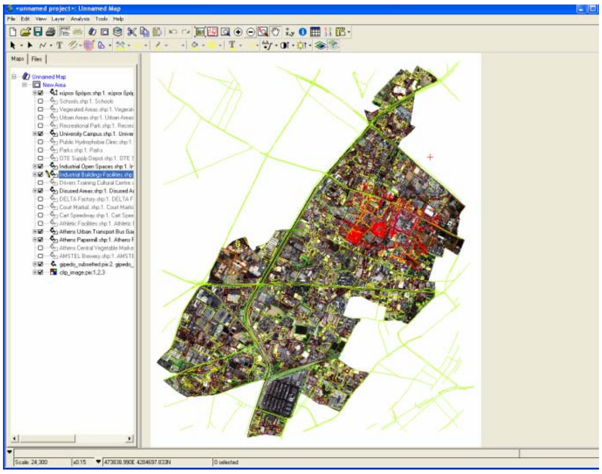

Figure 3: Overlay of town planning polygons (red) onto IKONOS Elaionas land-use extractions.

Results

There were many constraints, which affected the accuracy of the classification of urban sites, such as the fragmentation of the land and mixed and multiple land uses. The maximum likelihood classification algorithm cannot manage the above constraints, because this does not take into account useful information such as texture, shape and context on the existed land-use classes. The need of an object-based classification algorithm rather than a pixel based classification algorithm might be the ideal tool for these kinds of urban complex [23]. The utilisation of IKONOS is definitely a useful tool for urban areas allowing not only in the extraction of special features but also, indirectly, the derivation of urban plans.

Spatial resolution plays an important role in the urban feature extraction applications where scale and class separability are of key issues at field level. High-resolution satellites such as IKONOS can be used in an operational mode for urban feature extraction. Greek urban planners exhibited a positive reaction to the image clarity and sharpness of the IKONOS satellite rather than the more close to artistic views of Landsat ETM or IRS-1C images. In that respect, and prior to any urban planning, program planners may consult IKONOS images to assess the necessary environmental, socioeconomic and ecological impact on the surroundings.

Figure 4 illustrates a proposed new development in the Elaionas area, which includes a football stadium, basketball halls, shopping centres and entertainment centres. Using an integrated computational environment such as a GIS helped with the simultaneous processing and use of the hierarchical relationships of information such as satellite-based thematic maps, ancillary map data and distribution of bioclimatic data. Deriving these results helped to determine (i) the spatial location of possible human intervention and (ii) the climatic conditions that influence them, so that possible scenarios of urban development with concurrent protection of the environment will be viable. The GIS indicated that special urban features such as the new stadium complex would have positive and negative socioeconomic, ecological and environmental impact on the Elaionas area.

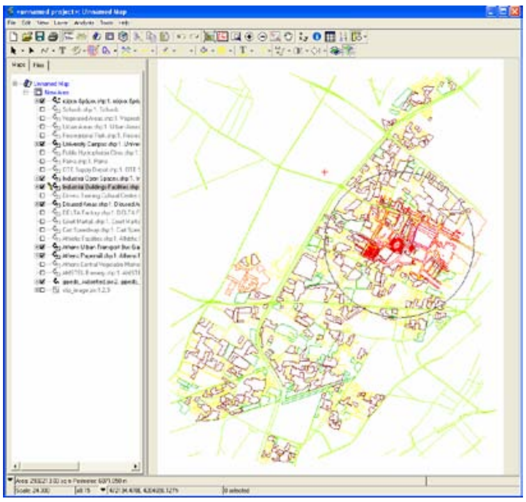

Figure 4: Buffer zone with 500m radius surrounding special urban features such as a football stadium and basketball halls, shopping and entertainment centres.

The decision on the exact location of the site and to build an urban complex of a total area of 148,188 sqm is not an easy decision to be taken by local authorities, especially in an area that has deteriorated and is characterised as the Athenian urban wasteland. The methodology showed that remote sensing and GIS can play an important role in the environmental assessment of urban building projects because they provide the visualisation and simulation platforms of existing and future statuses that will be developed after the human intervention [25]. The need for more or less open space, green areas, flexible transportation, infrastructure and utilities networks improvement, sustainability or not of the aesthetic impact, the reduction of air and noise pollution and the increase of the recreational and entertainment character that are associated with a new urban building project are all accessible via a desktop screen and they are just a click away. It is, therefore, a useful tool for managerial/environmental action plans and scheduling of projects in environmentally polluted areas.

CONCLUSIONS

In urban planning, decision and policy makers are often faced with the problems of dealing with systems in which natural and human factors are interrelated and lack of realistic representations of reality. A good decision, however, is first of all a well-informed decision. In order to carry out urban planning and development tasks, adequate spatial databases are needed.

The present article presents research, which aims to improve perception on how remote sensing and spatially-related technologies can provide planners, managers, engineers, and analysts with information that can be used to improve urban environment planning and maintenance efforts. The ultimate aim is the protection of the environment and contribution to sustainable development. The research hypothesis is based on the ability of very high spatial resolution data being able to produce high resolution maps (such as urban thematic maps), thus discriminating and mapping the urban complexes with the accuracy of $\pm$ 2 metres. In this way, the various urban land-use features can initially be extracted and environmental impact to/from an urban building can subsequently be assessed.

The methodology was applied in a real case study, the Elaionas area in Attica, Greece, and the impact of a proposed new development, including a football stadium and associated facilities, has been evaluated. Indeed the methodology has demonstrated that remote sensing and GIS can play an important role in the environmental assessment of urban building projects because they provide the visualisation and simulation platforms of the existing status and status that will be developed after the human intervention. It is, therefore, a useful tool for managerial/environmental action plans and scheduling of projects in environmentally polluted areas.

GISs and remote sensing technologies are employed mainly to provide information concerning the sensitivity of the existing environment, i.e. storing and visualising data, but also for data modelling and analysis. Many of these applications use basic GIS functions such as map production, buffering and overlaying. The use of GIS and remote sensing as a tool for data modelling and analysis is also well spread. However, most cases address a particular environmental application rather than provide a generally applicable approach. Planners and decision-makers, however, usually require more than one environmental process to be considered in a more than a particular application. The transition from multiple independent models to a single unified, generally applicable framework is clearly an ambitious objective and the present methodology with the use of GIS and remote sensing appears to provide an obvious platform.

Clearly, GIS and remote sensing have become an attractive response to difficulties such generation and management of environmental data and potential impacts, as well as spatial variations. Despite the increased number of applications and the well-acknowledged results of the implementation of such technologies in environmental decision-making, widespread access to and use of spatial information is still a problem in Europe [18]. Unfortunately, the technical and socio-economic characteristics of spatial information make the problems of coordination, information gaps, undefined quality and barriers to accessing and using the information significantly intense.

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