THE USE OF SATELLITE IMAGES IN THE DELIMITATION OF URBAN AREAS

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Summary:

Traditionally researchers interested in examining the internal dynamics of large scale urban areas have in the first place needed to determine a methodology for delimiting and/or defining the spatial extent of such areas. Within Western Europe there is a clear absence of common formal criteria for the delimitation of metropolitan areas, something which does nothing to facilitate trans-national comparisons. By contrast, in the United States for many year the Census Office has played a leading role in the evolution of criteria for the definition of metropolitan areas. Under the INTERREG IIC European Union initiative, researchers in South Western Europe adapted the US methodology based upon travel to work flows, for the delimitation of the principal metropolitan areas of the region.

However today the increasing availability of satellite images is becoming instrumental in geographical applications, offering a reliable tool for decision making in territorial management. For example the SPOT 5 satellite offers the possibility of producing images of large scale territorial areas (60 km by 60 km) with a resolution of 5m or 2.5m. Such resolutions allow interpretations at scales of 1:25,000 and 1:10,000, scales which permit the monitoring of the dynamics of major urban areas. This paper refers to a recently commenced research project being carried out by the Universitat Politècnica de Catalunya and the Mancommunitat de Municipis de l’Àrea Metropolitana de Barcelona forming part of the SPOT 5 Application and Validation Programme, addressing the urban dynamics in and around the metropolitan area of Barcelona over the period 1995/96 – 2003.
1. The spatial extent of metropolitan urban regions

The lack of homogeneous criteria for the definition of ‘metropolitan urban regions’ does nothing to add to the ease of making cross-comparisons at the European level. However in the case of the INTERREG-IIC project aimed at reaching an understanding of the territorial and functional characteristics of the metropolitan system of South Western Europe, a common methodology was agreed between the three partner countries of Spain, Portugal and France, in order to allow a cross-border comparison of the respective metropolitan urban regions within the territory of South-Western Europe. This methodology based upon that used by the Bureau of Census in the United States, drawing upon travel to work flows. (Office of Management and Budget, 1990)

Here a central municipality with at least 50,000 inhabitants is identified, in which at least 15% of the economically active residents from adjoining municipalities are employed. Successive aggregations or iterations to determine three metropolitan rings take place to arrive at the definition of a metropolitan area. There is normally a pre-condition that the overall metropolitan area has a minimum population of 75,000 inhabitants. However in the Spanish case, for political reasons, only the principal agglomerations with populations in excess of 500,000 persons were studied. Suffice to say this methodology was applied to the twelve areas studied at the metropolitan level of analysis within this INTERREG-IIC project: Bordeaux, Montpellier and Toulouse (France); Barcelona, Bilbao, Madrid, Málaga, Sevilla, Valencia and Zaragoza (Spain); and Lisboa and Porto (Portugal). See Figures 1 and 2 for the resulting metropolitan areas for the cases of Barcelona and Toulouse.

Figure 1: Metropolitan area of Barcelona, according to CPSV (2001)

Figure 2: Metropolitan area of Toulouse

2. Urban sprawl

According to the METREX Network throughout Europe, the metropolitan regions are all facing similar problems of economic change, social cohesion, urban sprawl, traffic congestion, city centre vitality and viability, and environmental damage and pollution. At the same time these areas and regions offer opportunities for renewal and regeneration, high quality urban life, and economic competitiveness. (METREX, 1999)

It is precisely this issue relating to urban sprawl, combined with compact versus disperse urban development, outward mobility and sustainability within the metropolitan urban region which together form one of the principal areas of research within the Centre de Politica de Sòl i Valoracions (CPSV) of the Universitat Politècnica de Catalunya (UPC). The CPSV together with the Mancomunitat de Municipis de l’Àrea Metropolitana de Barcelona (MMAMB) have recently begun work for the French Centre National D’Etudes Spatiales (CNES) as

1 The Network was founded April 1996 by representatives from many of the120 or so metropolitan regions and areas of Europe, bringing together practitioners with a common interest in spatial planning and development at the metropolitan level. The twin purposes of the Network are to promote the exchange of knowledge between practitioners on strategic issues of common interest and to contribute the metropolitan dimension to planning at the European level. (See http://www.eurometrex.org/)
part of the Spot 5 Application and Validation Programme (SAVP), aimed at testing and evaluating Spot data for operational applications on urban planning, urban land occupation and the urban environment etc.

The principal objective of the SAVP case study relating to Barcelona is to assess and verify the increased accuracy afforded by the new generation of satellite images from SPOT 5, for the monitoring of key urban development issues both within the confines and beyond the edge of Barcelona’s metropolitan area. In recent years Barcelona’s metropolitan area has witnessed significant growth in peripheral urban development, or urban sprawl, with progressively increased land consumption, matched by a decrease in population in core. The SAVP research proposal therefore seeks to assess the extent to which the satellite data can aid in the quantification and analysis of the phenomenon of ‘peri-urbanisation’. In order to be able to test the data to the maximum, a dynamic approach is being taken, whereby data from the mid-1990s (resulting from SPOT 3 or Spot 4 images) will be compared with present-day data.

The remainder of this paper sets out some of the key aspects of this joint project with the CNES which relate to questions of analysing urban sprawl in Barcelona’s metropolitan area in the period 1995/96 to the present day.

3. Satellite imagery

It is irrefutable that Earth observation is a modern science, which studies the Earth’s changing environment, through “remote sensing” tools such as satellite imagery and aerial photography. (EEA, 2002) A report published by NASA in 2001 highlighted the fact that the advances in satellite-based land surface mapping are contributing to the creation of considerably more detailed urban maps, offering planners a much deeper understanding of the dynamics of urban growth, as well as associated matters relating to territorial management. (NASA, 2001) Furthermore in recent years, thanks to the increases in the average resolution of such satellite images (2.5 metres in the definition of objects in the case of SPOT 5), the technology has become increasingly more efficient in all aspects relating to Earth observation.

Within the European context, the most recent comparable study of this nature is that of the MURBANDY/MOLAND project (Monitoring Urban Dynamics / Monitoring Land Use Changes) which has used “remote sensing”, the results of which have been published by the European Environment Agency (EEA, 2002). This project drew together a network of European partners and sought to measure and assess urban dynamics, through the creation of a land use data base, for a range of European cities and urban regions, including Bilbao. These data bases combine environmental, social and economic information, in order to reach a better understanding of the characteristics and dynamics of urban growth and the changes related to land use, such as transport and energy infrastructure, and the changes in agriculture and natural areas. The results show the spatial evolution of a group of urban areas, with the objective of proposing a methodology for strategic monitoring of the environmental impact of urban development.

It is relevant to highlight the fact that the Report of this project suggests that “urban growth and sprawl is a pertinent topic for analysis and assessment today. The environmental impacts of urban sprawl and the extent of urban problems have been growing in complexity and relevance, generating strong imbalances between the city and its hinterland. The need to address this complexity in assessing and monitoring urban planning and management processes and practices is strongly felt.” (EEA, 2002, p.7)

The MOLAND methodology, a more advanced version than MURBANDY, has created the data bases for four periods, for the 1950s, the 1960s, the 1980s and the 1990s, through the interpretation of satellite images, principally IRS images, but in some cases IKONOS and SPOT images. (Lavalle et. alt., 2002) It is important to note that the nomenclature adopted for the “remote sensing” was a more extensive version of the CORINE legend. One of the fundamental differences between Murbandy/Moland and Corine, apart from the greater precision with the level of detail, is that with Murbandy/Moland it is possible to make the distinction between different land uses. By contrast, Corine is more limited related to the distinction between different land classifications. This methodology has enabled the evaluation of “urban sprawl” for the 25 case studies, understood as the percentage increase in the urbanised surface area during the period under review.

3 EUROPEAN ENVIRONMENT AGENCY (2002): Towards an urban atlas: Assessment of spatial data on 25 European cities and urban areas, EEA, Copenhagen.
4. Delimitation of urban agglomerations

For the purpose of this study, what is of perhaps greater interest than using the delimitation of the functional urban region of a metropolitan area as the basis for examining the dynamics of urban sprawl, is that of a more morphologically based urban agglomeration. An urban agglomeration here is simply defined as the portion of the metropolitan area which shows a greater proportion of developed land, as well as concentrating the larger part of the metropolitan population. Different population density thresholds may be applied to determine the said urban agglomeration.

The use of demographic density has the inconvenience of not recognising the areas characterised by an accused specialisation of economic activity, but which can be scarcely populated. At the same time they can have difficulties in the case of municipalities characterised by the abundance of urban fabric of low density (widely separated single unit dwellings), as well as those whose municipal boundaries are extremely wide with extensive areas of undeveloped or natural land, although undergoing significant development.

In order to try to overcome these problems, the project seeks to define the urban agglomeration by way of remote sensing techniques or satellite photography recognition. This involves the use of SPOT images, proportioning a pixel resolution of 2.5 m, for the establishment of a grid-network over the territory with cells of say 100m x 100m. An automatic process will determine the percentage of developed land in each of the said cells. Starting from the “centre” and working out towards the “periphery”, the gradients of development will be established. Clearly there exists a break off point at which the city or urban agglomeration gives rise to a wider territory or metropolitan periphery, which although characterised by a strong functional interaction with the rest of the metropolitan area, highlights the weakness of the development process in relation to the dominance of the natural environment. Within the urban agglomeration however, the developed area is the dominant form, with the areas of natural and or open space forming the “islands”.

Figure 3: Example of progressive outward reduction in residential development leading to the definition of the urban agglomeration

5. SPOT 5 satellite images

One of the novel aspects of this project lies in the acquisition and geo-referenced treatment of the satellite images for the analysis and characterisation of the process of urban sprawl over the time period. The satellite images for Barcelona will allow for the analysis of the urban form, making use of a standard methodology easily applicable to other urban agglomerations. However they form an essential element of the project in three principal phases:

- at the moment of defining the “urban agglomeration”
- at the moment of determining the process of “urban sprawl” produced over the study period, and
- at the moment of studying the land uses in the different outer metropolitan rings, with regard to residential, industrial and commercial activity.
One of the objectives of the project is to set in motion the most automatic methods possible, in order to demonstrate the specific interest of satellite images: the coverage of extensive areas, method reproducible between different zones. The SPOT 5 satellite is the only one currently capable of offering images of large areas (60 km by 60 km) with a resolution of 5 metres or 2.5 metres. These resolutions allow interpretations at scales of 1:25 000 and 1:10 000, scales totally adapted to the problems of territorial management. The 2.5 m colour images present certain problems for the image treatment: in the first place, in terms of the treatment capacity, in view of the sheer magnitude of some 1.7 Gigs, and also in the automatic extraction of assimilated information for a GIS. Figures 5 and 6 illustrate in the case of Toulouse the spatial extent and level of detail of the new generation of Spot images.

5.1 Definition of the limit of the urban agglomeration

The process for the definition of the urban agglomeration can be divided into some 5 stages:

- the automatic identification of the ‘developed’ uses.
- manual correction, if necessary, of the aforementioned ‘developed uses’ (particular problems, for example such as gravel pits).
- the application of a criteria of spatial continuity (distance inferior to 200m) in order to obtain the physical footprint of the agglomeration.
- the combination of this footprint and the administrative boundaries of the municipalities of the zone.
- the calculation of the respective contribution of each municipality to the urban footprint. These calculations will be realised through iterations, from a starting point (the centre of the municipality) and over ever increasingly greater distances. The rupture in the values of the successive results calculated allowing for fixing the administrative boundary of the agglomeration.

The images will be able to be segmented and classified at different levels. The objects created in this way are linked, in a similar way to a topology in GIS.

5.2 The “urban sprawl” process

This aspect will be addressed through a comparison of the data for the satellite images at the two points in time under review – 1995/96 and 2003 – by way of quantifying the area of land which has been developed.

The analysis will be carried out for the following territorial ambits of Barcelona’s metropolitan area:
• the central core area
• the remainder of the urban agglomeration
• the metropolitan periphery
• the individual municipalities.
• the metropolitan rings (< 10, 10-20, 20-30 y > 30 km).

The examination of developed land will enable the identification of and distinction between the following uses:

• residential (differentiating between “high” and “low” density residential development).
• economic activity (distinguishing between industrial, commercial and office park uses).
• infrastructures (roads, open spaces, ports, airports and other infrastructures).

The principal indicators to be used in this phase of the study will be along the lines of the following:

• % of developed land in relation to the sum of the administrative ambit under consideration.
• % of land developed for each use, as a proportion of the total developed land.
• quantity of developed land per inhabitant, per household unit and per dwelling unit.
• quantity of residential land per inhabitant, per household unit and per dwelling unit.
• “intensity” of inhabitants, household units and dwelling units per km² of developed land.
• quantity of developed land per local job.
• quantity of land occupied by economic activity per local job.
• “intensity” of jobs per km² of developed land.

5.3 Land use study

Finally this part of the assessment will seek to examine the spatial distribution of economic activities, as well as those of a residential character, in the different ambits of analysis as previously referred to: the metropolitan centre; the rest of the urban agglomeration; and the metropolitan periphery. It will be necessary to take up again the basic classifications carried out previously, but this time going further in an attempt to distinguish the residential types uses (and here distinguishing between disperse and compact residential development), from the industrial and commercial uses. It is not expected to localise all the activities, but at least those sufficiently extended geographically (industrial uses and commercial centres), i.e. those which have regrouped in physically differentiated activity zones.

6. Conclusions

The novelty of the research lies principally in the potential to apply for the first time in Spain, the analysis of up to date satellite images for the exact quantification of urban developed land within the metropolitan area of Barcelona. Clearly remote sensing offers the possibility of monitoring the process of urban development in “real time” through the use of automatic algorithms. At the same time the project will incorporate the use of satellite images in the analysis of different land uses. It is considered that the scale of precision equivalent to 1:10 000, and the detailed description of land uses, will allow for a qualitative change in the evaluation of the use of “remote sensing” techniques in the analysis of the urban space.

For all of these reasons, it is considered that the interest of the study is beyond doubt, not only within the immediate local planning and decision making environments, but well beyond in Spain and other countries as well.

References

