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Early Warning Systems for Regional Science

- Monitoring Land Use Changes Using GIS -

Rui Pedro Julião

Universidade Nova de Lisboa

Departamento de Geografia e Planeamento Regional

rpj@fcsh.unl.pt

Abstract

Major infrastructures, as the new bridge across Tagus river in Lisbon (Vasco da Gama Bridge), are a significant driving force shaping land use and land cover, specially in what concerns urbanisation. Subsequently, all the regional socio-economic system will register huge transformations.

Monitoring land cover changes can give technicians and politicians an early warning system towards socio-economic transformations. While socio-economic data is quite hard and expensive to achieve, geographical data is becoming more and more accessible. This availability together with the expanding GIS spatial analysis capabilities provide the toolbox for a new generation of regional science methods.

This paper will focus on the methodological issues regarding monitoring land cover changes using GIS and its relevance for regional science.

First, we will start by giving a brief context about land use/cover and socio-economic systems. Then, it will be presented the methodological core of monitoring systems for land cover changes with the example of a project being developed for the Vasco da Gama Bridge. Finally, we will draw some concluding remarks towards land cover monitoring systems as an early warning system for regional planning.

1.   Introduction

If one considers Regional Development as a process, GIS (as a supporting tool for regional development) can be a very useful tool in its different phases. The process approach leads to establishing four major phases:

– Analysis/Diagnosis.

– Proposal/Decision.

– Public Discussion.

– Monitoring/Evaluation.

In these different phases GIS's functionalities are explored according to the specific needs. The figure 1 illustrates the relationship between GIS functionalities and the different phases of the Regional Development Process.

Figure 1. - Regional Development Process and GIS
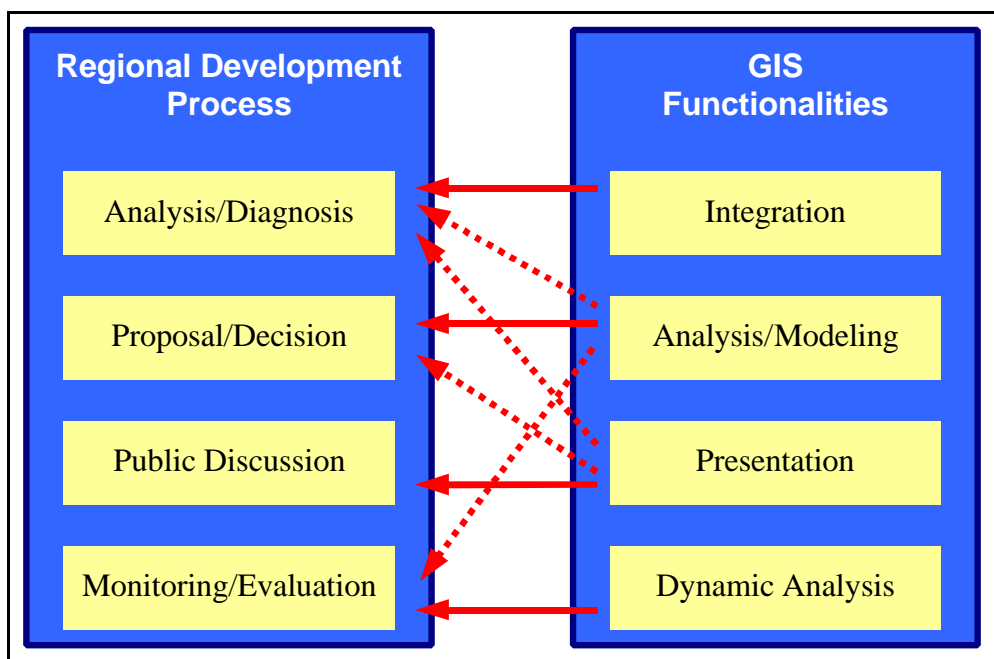
The first phase, Analysis/Diagnosis, makes use of the high performance of GIS as a data integration tool. Territorial knowledge and spatial preview can be improved by the use of this new technological methodology.

Proposal and Decision, the second phase, is perhaps the most sensitive moment in all this process. A GIS spatial analysis capability makes complex territorial modelling easier.

The third phase, Public discussion, both of policy decision and results benefits also from the GIS graphical presentation capacity.

Last, but not the least, Monitoring and Evaluation, the fourth phase, can also be implemented with the support of the GIS dynamic evaluation tools which will maximise its efficiency.

The final question related with the theme of this paper is why monitoring land cover changes in a regional development context ? The idea is that the development trends can first be detected through physical changes in land cover structures and if we can link that information with traditional data sets it provide us a early warning system of development trends.

2.   *Monitoring Land Cover Changes*

Behind land cover analysis there should be three major concerns:

- Where did it changed ?

- How did it changed ?

- What is the changing process ?

After knowing the answer for these major concerns, one should address other questions that can be answered with the integration with other information domains: what will change ?, where will it change ?, How will it change ? and when will it change ?).

The methodological approach here proposed is based in the assumption that:

- the analysis process will stick to the 1990 and 1998 coverage;

- there is cartographic and topologic compatibility between the two coverages.

Figure 2. – Comparative analysis of two land cover coverages
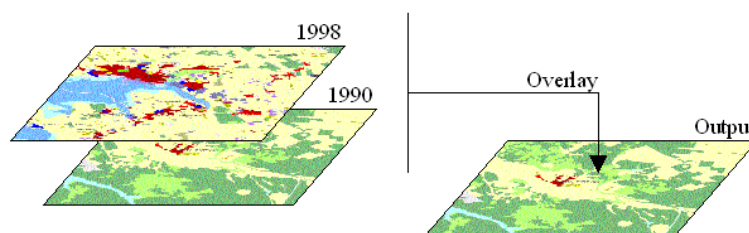
Adapted from: JULIÃO, R. P. e CARDOSO, J. F.; 1999

2.1.   Where did it changed ?

The general purpose of this analysis is to detect where did land cover changes occured between the to dates, identifying the new cover typology.

First, by a simple overlay process, all the areas that have registered a change between 1990 and 1998 are isolated. Then they are measured and characterised by each legend item.

Along with all cartographic outputs of this analysis, it is possible to have a land cover changes table with records of all new areas aggregated by each legend item.

2.2.   How did it changed?

This second analytical vector uses the same process as the first one and it help us to understand how did land cover changes occurred.

The analysis is supported by a map with a cross legend. In rows we will have the new land cover classes and in columns the old ones. The results are a map showing the changing trends and a table with all the records.

Although it is possible, and necessary, to carry the production of the map it is not an easy document to work with, at least with an extensive legend.

This analytical vector should also contain a second level analysis done by the integration of interpretative chart of the two original land cover maps. The legend should contain the most important generic land cover items, such as:

- Urban built up areas (Population density = 10 inhab/ha)

- Semi-Urban built up areas (Population density = 5 and < 10 inhab/ha)

- Disperse built up areas (Population density = 2.5 and < 5 inhab/ha)

- Non built up areas (Population density < 2.5 inhab/ha)

2.3.   What is the changing process ?

The analysis process continues with the production of an interpretative map that contains the explanatory trends of land cover change. The legend items are just the few more important changing processes of land cover (in the next table and figure you can see examples of land changing processes).

## Table 1 - Land cover changing processes map legend items

Category	Subcategory	Description
Areas with transformation	Expansion	Built up area growth adjacent to existent areas.
	Filling in	Growth of built up density by filling in the vacant territory inside built up perimeter or by shifting the building typology.
	Emerging	New built up areas with a significative extension and density not connect with pre-existent urban areas.
	Dispersion	Appearance of isolated buildings out side the built up perimeter.
	Potential agricultural abandonment	Replacement of agriculture related coverage with others connected with probable future urban uses.
Areas without transformation	---	Areas without transformation

Adapted from: JULIÃO, R. P. e CARDOSO, J. F.; 1999

Figure 3 - Land cover changing processes examples

Example 1: Expansion

By comparing the two pictures it is clear the expansion of the built up area to its contiguous territories.
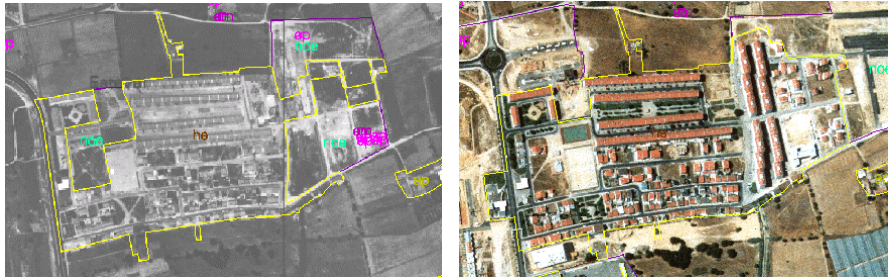
Example 2: Filling in

In this example it is clear that the growth inside the built up perimeter was significative and the perimeter is approaching its building capacity.

Example 3: Emerging

The emerging areas are illustrated here by this new road/street infrastructure that is replacing the agricultural area.
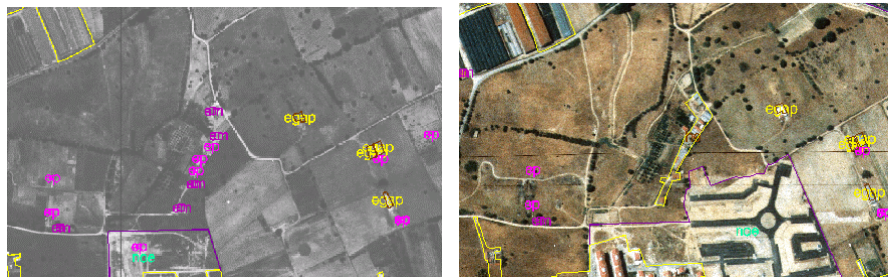
Example 4: Potential agricultural abandonment

This is the first step to become a built up area. After being purchased by building companies and while waiting for municipal permits the agriculture coverage is neglected and the parcel can stay like this for a long period.

Adapted from: JULIÃO, R. P. e CARDOSO, J. F.; 1999

To get a synthetic perspective of the land cover changing process it is possible to produce some indicators.

Table 2 - Land cover changing process dynamics indicators

| Indicator	Formula	Description
Land cover changing rate (T_t)	$T_t = \dfrac{A_{mod\,ificada}}{A_{total}} \times 100$	Percentage of land cover that has changed between 1990 and 1998. It is possible to estimate the land cover changing rate by each legend item or its global value. It is also possible to estimate the value for each territorial unit (concelho, freguesia, subsecção, etc.).
Built up area rate (T_e)	$T_e = \dfrac{A_{edificada}}{A_{total}} \times 100$	Percentage of built up area.
Built up area variation rate (TV_{Ae})	$TV_{Ae} = \dfrac{Ae_{1998} - Ae_{1990}}{Ae_{1990}} \times 100$	---
Residential area variation rate (TV_{Ah})	$TV_{Ah} = \dfrac{Ah_{1998} - Ah_{1990}}{Ah_{1990}} \times 100$	---
Industrial area variation rate (TV_{Ai})	$TV_{Ai} = \dfrac{Ai_{1998} - Ai_{1990}}{Ai_{1990}} \times 100$	---
Residential area filling in index (IC_{Ah})	$IC_{Ah} = \dfrac{\sum (Ah_n \times 3 + Mh_n \times 2 + Bh_n \times 1)}{\sum (Ah_n + Mh_n + Bh_n)}$	The result is between 1 (low filling in) and 3 (high filling in).
Industrial area filling in index (IC_{Ai})	$IC_{Ai} = \dfrac{\sum (Ai_n \times 3 + Mi_n \times 2 + Bi_n \times 1)}{\sum (Ai_n + Mi_n + Bi_n)}$	The result is between 1 (low filling in) and 3 (high filling in).
Disperse edification rate (T_{ed})	$T_{ed} = \dfrac{A_{edif.dispersa}}{A_{edificada}} \times 100$	Percentage of disperse edification.
Agricultural area variation rate (TV_{Aa})	$TV_{Aa} = \dfrac{Aa_{1998} - Aa_{1990}}{Aa_{1990}} \times 100$	---

Adapted from: JULIÃO, R. P. e CARDOSO, J. F.; 1999

2.4. Using Land Use Plans

The analysis of building trends can only be fully accomplished if one considers the information regarding land use plans and the information regarding building permits. The basic methodology to integrate these two components with the land cover information is explained in the next schema.

Figure 4 - Land cover analysis schema
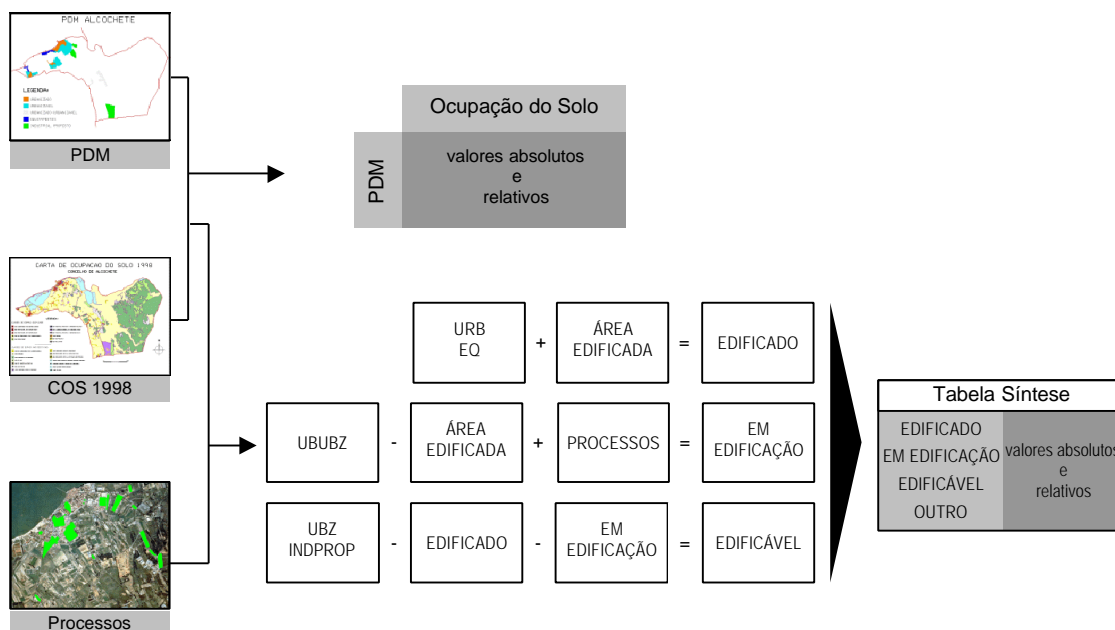
Adapted from: JULIÃO, R. P.; 2000

The general purpose of integrating the three components is to enable a better explaation of the territorial dynamics. First, by comparing the PDM[1] (Municipal Master Plan) and the land cover it is possible to evaluate how the plan's implementation is being done. This information is vital for the future plan. Second, by joining the building permits[2] it is possible to get the global information and establish three degrees of commitment. The built up area (territory already occupied), the area under construction (territory already committed by permits) and the area of expansion (territory already committed by plans).

This methodological approach was tested in the municipality of Alcochete.

A quick look at the major land cover changing indicators shows that, although this municipality has a vast non built up area, the growing rate if high (30%). This high value together with the decrease of the filling in index, are a sign that the changing of built up areas is conducted by an expansion phenomena.

Table 3 - Land cover changing process in Alcochete – Some indicators

$TVae_{90\text{-}98} = 30.37\%$	$TVah_{90\text{-}98} = 27.46\%$	$TVai_{90\text{-}98} = 56.58\%$
$Te_{1990} = 2.81\%$	$ICah_{1990} = 2.53$	$ICai_{1990} = 2.40$
$Te_{1998} = 3.66\%$	$ICah_{1998} = 2.51$	$ICai_{1998} = 2.38$

Adapted from: JULIÃO, R. P.; 2000

The overlay between the land cover map and the PDM produces the following maps and the table from next page, where it is possible to know the structure of land cover for each plan's class.

Figure 5 - Territorial degrees of commitment

Espaço	Área (ha)	%
🟥 Edificado	470.21	4.85
🟦 Em edificação	135.61	1.40
🟩 Edificável	409.52	4.22
🟩 Outro	8,685.25	89.53
Total	9,700.59	100.00
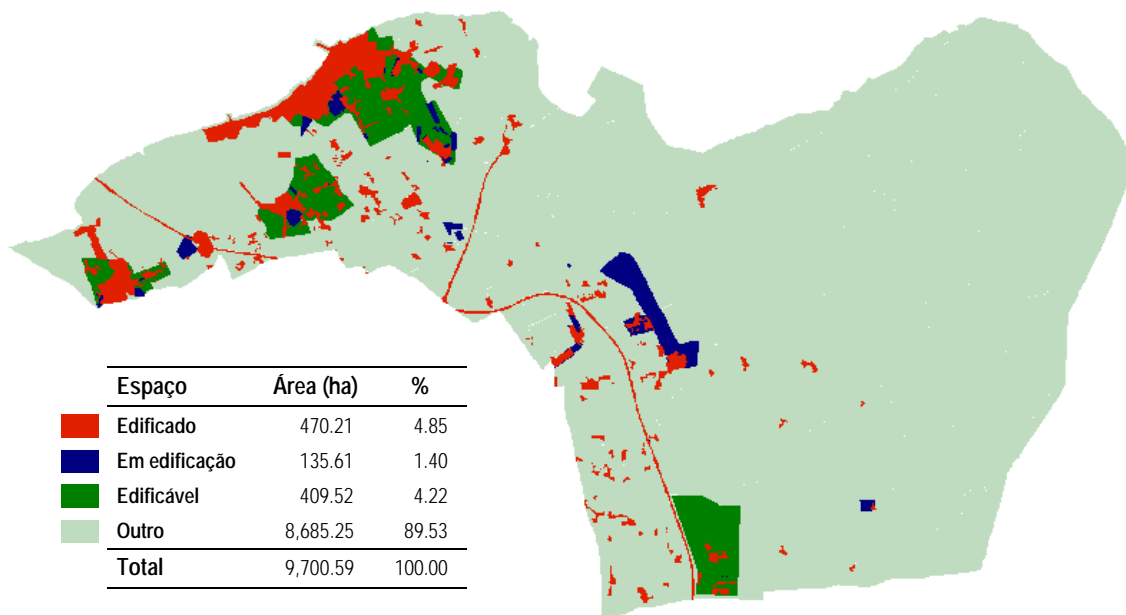
Adapted from: JULIÃO, R. P.; 2000

Table 4 - PDM of Alcochete and Land cover

	PDM					Unit: %
	Built up area	Proposed Urban	Other Urban	Proposed Industrial	Facilities	Other
Residential	60.8	12.6	13.2	0.0	0.9	0.2
Industrial	3.1	0.3	3.6	15.0	9.9	0.3
Facilities	10.0	0.4	0.8	0.0	6.1	0.7
Other	26.1	86.7	82.4	85.0	83.1	98.8
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Adapted from: JULIÃO, R. P.; 2000

3. *Integrated Analysis*

The final step of this approach is to establish an integrated indicators' system that enables the relationship between the four major themes regarding development. Once this system is implemented it is possible to identify the driving forces and start making analysis, such as if ... then ...

The four themes are:

1. Territorial dynamics characterisation
    1.1. Land cover change
    1.2. Municipal Planning and building permits
    1.3. Building dynamics
    1.4. Accessibility and transportation
2. Socio-economic dynamics characterisation
    2.1. Population
    2.2. Economic activity and employment
3. Environmental and quality of live dynamics characterisation
    3.1. Natural and environmental sensitive areas
    3.2. Basic infrastructure network
    3.3. Facilities
    3.4. (Re)Qualification
4. Investments

The analysis of each theme should not be done in an isolated context. Although, it is possible, this is not recommended because the side effects are lost. Each one has its specific contribution for the general purpose of knowing the territorial and socio-economic impact of the new bridge.

4.   Concluding Remarks

Why monitoring land cover changes in a regional development context ? The idea is that the development trends can first be detected in what is happening at the territory and, only after, these effects are extended to other domains, such as economic activity, etc.

The Vasco da Gama Bridge is an important infrastructure that will induce several territorial transformations. If the North side of the river is quite developed, the South side entry is located in an area with a very low human occupation. This South side of the river is known for its low urban density and a very sensitive ecological system.

The knowledge of this peculiar situation was the motivation for a more detailed study of the environmental and socio-economic impacts of the bridge and also it provides a very good field test are for this methodological approach.

Notes

1) The information regarding the PDM was collected by DGOTDU and it onlay contains the following classes: Urban area (URB);

Proposed Urban (UBZ);

Other Urban (UBUBZ);

Proposed Industrial (INDPROP);

Facilities (EQ).

2) The following building permits were considered: Residential plots, Turistic buildings, Commercial buildings and Industrial buildings.

References

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