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Analysis of landscape change following the construction of the Alqueva dam, southern Portugal – Approach and methods

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Abstract: European landscapes are under enormous pressures related to the major challenges facing our society. In our research we intend to analyze recent landscape change in the Alqueva dam watershed and predict future scenarios in terms of land use/cover and landscape configuration. The multi-agent systems modeling of land use/cover change (MAS/LUCC) are tools that combine methods like multi-criteria evaluation (MCE) and cellular automata (CA), being able to go beyond the mere analysis of land use change, permitting a more and more proximal approach to landscape itself. This article presents a review of the conceptual theory and application of MAS/LUCC as a way to define a methodology of analysis of recent changes in the Alqueva Dam Watershed and prediction of future scenarios for 2025, 2050 and 2100. This landscape unit has a high potential to change not only related with the dam construction, but also by the consequential territorial options in the Regional Plan for the Surroundings of Alqueva's lake (PROZEA).

Keywords: Landscape change, simulation models, dam, watershed, soil erosion, climate change

1 Introduction

European landscapes are under enormous pressures related to the major challenges facing our society: climate change, urbanization, countryside abandonment and concentration of population in cities, energy demand and infrastructures construction. These changes affect water quality and supply, health and food provision. Changes in our lifestyle and consumer habits, an increasing need for energy, food and biofuel production and shifting demographic developments are placing considerable demand on the environment, threatening landscapes and ecosystems at an alarming rate. Climate change will compound these pressures, increasing the vulnerability of populations and their ecosystems.

Over time, Man has shaped the Earth's surface, through the use and occupation of land, interacting with nature and building what we call the landscape. However, the rhythm of global, regional and local land use/cover change (LUCC) in the last decades has clearly accelerated, result of a conjunction of environmental, social, economic and institutional factors favorable to the modification of landscape structure, mostly sustained by the intensification of land use or its abandonment. Sudden land use

change could have unexpected impacts like soil erosion, biodiversity depletion or pollution, among others, which are difficult to deal with, given the fugacity of its occurrence. In the present times, there is thus the challenge and need to quickly and efficiently study changes in land use to support information gathering to predict its consequences, proactively contributing to sustainable landscape planning.

On this subject, it's acknowledgeable the prevalence and importance of multi-agent systems of land use/cover change (MAS/LUCC) that combined with, in many cases, the technology of Geographic Information Systems (GIS), represents an useful tool to analyze the modification of the landscape in the past, simulate future land use change and predict potential implications. MAS/LUCC are adequate instruments for understanding the functioning of land use systems and building scenarios of future landscape structure.

The analytic exploitation of theory and practical applications of MAS/LUCC provide the background to the definition of an accurate methodology to study a landscape with a high

potential of change: the Alqueva Dam Watershed in the Alentejo Region, Portugal.

Initiated in 1995, the Alqueva dam created the largest artificial lake in Western Europe (started to fill in 2002), inducing land use dynamics due to tourism development, intensification of irrigated farming and biomass production, as well as climate change [1]. These dynamics, visible in late and present times, are according to the pretensions for future, defined mainly by the Regional Plan for the Surroundings of Alqueva's Lake (PROZEA). These land use change dynamics can have implications on soil properties, causing erosion, and potentially increasing sediments deposition at the bottom of the lake, increasing the risk of early dam silting up. The construction of scenarios represents a valid approach to predict not just change in land use, but also the impacts of land use alterations [2] like soil erosion and deposition.

The Revised Universal Soil Loss Equation (RUSLE) is the most consensual equation to empirically estimate annual soil loss in agricultural watersheds [3]. The equation is: $A=RKLSCP$ (1), where A =potential erosion (computed annual average soil loss in $t\cdot ha^{-1}\cdot year^{-1}$), R =rainfall and runoff erosivity factor, K =soil erodibility factor, LS =slope length and gradient factor, C =vegetation cover factor and P =vegetation control practice factor [3]. The simulation of land use change by MAS/LUCC can contribute to estimate changes in factors C and P .

In this paper we review the theory and application of MAS/LUCC methodology within the framework of our study.

2 Simulation of Land Use/Cover Change: a review

2.1 Models, Land Use/Cover and Landscapes

The spatial analysis through GIS is often characterized by static dimension and determinism, not integrating the correlation between the landscape structure and the processes that modify it, for example, human actions and motivations [4]. GIS models are driven mostly by static spatial variables for the simulation of land use change, not including non-linear variables [4]. Therefore, to a more congruent analysis and modeling of land use change it is necessary to take into account not only spatial data, but also hierarchical relationships, social and economic factors, and the autonomy of human action in order to express a close approach to landscape dynamics.

It is essential to differentiate the concepts of landscape and land use. The landscape concept is *holistic and integrates ecologic, cultural, socio-economic and sensorial dimensions – landscape is a dynamic system where the environment and cultural factors interact and evolve together, determining and being determined by the global structure, which results in a particular configuration: slope, plant cover, land use and urban occupation, which results in a specific unity and character* [5].

As a dynamic system, the landscape is not immutable, evolving over time, and the land use/cover change is just a part of it. On other hand, research for new, increasingly integrated and sustained approaches, models and methodologies, comes from the need of experts to deal with the occurrence of rapid changes in the landscape and the emergence of its consequences.

In this context, over the last years MAS/LUCC have played a key role in presenting more concerted computational models that integrate both numerical-quantitative and symbolic-qualitative components [6]. According to this, MAS/LUCC combine two aspects: the first is a cellular model which represents the landscape change and the second corresponds to an agent-based model that reflects the decision making of the landscape actors [6]. However, the use of these models does not exclude GIS methods, quite the contrary. In most cases, GIS methods are complementary and unsubstitutable part of the simulation process.

2.2 Main MAS/LUCC models

The MAS/LUCC has various typologies of models, namely [6]:

- *Equation-based models*: only use mathematical principles, not reaching the effective interpretation of landscape dynamics;
- *System models*: incorporate the relationship between human and ecological factors, but do not represent them spatially;
- *Statistical techniques*: a simplistic technique, preferentially used in economics and geostatistics; includes the regression methods;
- *Expert models*: based on the knowledge of specialists and supported by qualitative methods, neglecting the quantitative analysis [6];
- *Evolutionary models*: apply the Darwinian logics in simulations, using, in most cases, neural networks [6];
- *Cellular models*: modeling is done by changing the states of cells (cellular automata units, each one representing land uses), incited by the

application of transition rules. The cellular automata has five basic elements: cell (basic unit), status (system attributes), neighborhood (cell's interactions), transition rules (behavior change of each cell) and time [7];

- *Hybrid Models*: result from the combination of various techniques – cellular models, statistical, and other [6].

Over the last years, cellular models have outstandingly improved the land use change approach. Representing a geospatial structure, cellular automata (CA) is a processing mechanism with characteristics that change over time based on its internal characteristics, rules and external input [8]. The land use alteration is given by the cell's interaction, whose change of state is derived from the conditions of the neighborhood and the adoption of transition rules in defined time periods. Often they rely on transition probability matrices of land use change as it happens in Markov cellular models, a congruent and simple way of scenarios construction.

Despite their easy application, the need of these models for consistent time series, as a basis of extrapolation, is not always feasible, especially when simulating recent or very distant land use changes. In these cases, there are few data, which can compromise the projection of the land use change dynamics, derived from the lack of a solid foundation. Therefore, the allocation of new land uses could be incongruent with the real dynamics of the landscape, just adhering to the mere spatiality of change. It is imperative to take into account the heterogeneity of the acting agents in the landscape, regarding not only the land use change itself, but also the many factors that influence it.

As such, it is common to combine CA models with new approaches that integrate other factors and using complex sets of hierarchical rules (Analytical Hierarchy Process – AHP) to differentiate the weights of decision making factors, as part of a multi-criteria evaluation (MCE) [9].

MCE consists of defining landscape attributes or factors and constraints, establishing respective criteria of suitability to change, usually following a Boolean approach. This means the constraints and factors are standardized to Boolean values of 0 (unsuitable to change) and 1 (more suitable) [9]. On other hand, AHP determines the weights for each factor, using a pairwise comparison matrix, which compares the importance of one factor to another, at last determining the more suitable areas to change [10].

The difficulty of studying complex systems like landscapes and their land use change dynamics

requires from MAS/LUCC a wider approach, for which a combination of methods is a solution.

2.3 Applications of MAS/LUCC

The application of these models is vast and not only multi-disciplinary, but also inter and transdisciplinary, going from natural resources management to, agriculture development, archeology or urban sprawl [6].

The analysis of land uses and the simulation of their modifications alerts for potential undesirable environmental consequences, consisting in a preferential instrument to support proactive and sustainable Landscape Planning [11].

Several studies have applied MAS/LUCC, which are presented based on the following examples:

- *Rural sustainability under threat in Zimbabwe – Simulation of future land use/cover changes in the Bindura district based on the Markov-cellular automata model* [12];
- *Potential impacts of agricultural expansion and climate change on soil erosion in the Eastern Arc Mountains of Kenya* [13].

The first study addresses the rapid changes in land use caused by deforestation in the Bindura district, Zimbabwe. The establishment of biophysical and socio-economic factors of influence (like elevation, distance to rivers, population density, distance to town centres, etc) through MCE and, consequently, their correspondence into weights by AHP, enabled the making of maps of differential potential transition or suitability of land use change. Using Markov chains, transition probabilities matrices were calculated for the 1973-1989-2000 period which combined with maps of potential transition made it possible for another method (MOLA – Multi-objective land allocation) to allocate simulated changes for the years 2010, 2020 and 2030. Given a gap between the end of the evaluation period (2000) and the date the study was conducted (2009) it was possible to prepare experimental scenarios from 2000 to a known date (2005) and compare results between the simulated and real landscapes which were used to validate the models and the overall methodology in order to improve future land use change forecasting [12].

In the second case, the simulation of land use change for the year 2030, driven by agriculture expansion and climate change in Eastern Arc Mountains of Kenya, led to the investigation of potential impacts on soil erosion using the RUSLE equation. The model was focused on temporal series of land use/cover to determine transition rules of cellular automata and on MCE of factors or

landscape attributes such as distance to roads, altitude, distance to rivers, protected areas, type of soils, slope, insolation, annual precipitation and distance to already established croplands [13]. It was possible to simulate the future landscape structure for 2030 and the definition of measures for motoring and regulate agricultural practices.

3 The Alqueva Dam Watershed: a landscape under rapid change

The Irrigation Plan for the Alentejo Region, south of Portugal, was prepared in 1957 with the purpose of developing this region socio-economically through the irrigation of more than 1000 km² [14]. At the same time, the discussion of the hydraulic use of the Guadiana River emerged. The construction of the Alqueva dam started only in 1995, beginning to fill in 2002 and reaching the maximum level in 2010.

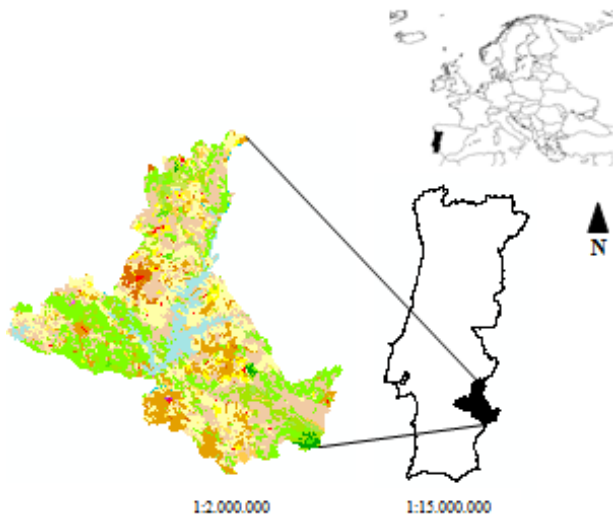


Figure 1 – Location of the Alqueva dam watershed.

Today, the Alqueva dam maintains Western Europe's largest artificial lake, covering an area of 250 km² with a reservoir's capacity of 4150 hm³ [14] (Fig.1). The visual impact of the lake is significant, exacerbated by the contrast of the presence of such a huge mass of water in a distinctly arid environment. The landscape is characterized by a set of islands and peninsulas in the immense lake, surrounded by units of agro-forestry systems, holm oak (*Quercus ilex L.*) woodlands and some olive groves, vineyards and agriculture (cereals and fodder plants) systems. Topographically, there are differences in altitude within the area (between 100 and 200 meters) [15]. The climate is mediterranean with continental influence, with hot and dry summers, and mild winters [14]. The annual average

precipitation in the Guadiana river watershed, where the Alqueva dam is located, is 561 mm [16].

Currently, the Alqueva landscape is experiencing evident land use changes, promoted by the Regional Plan for the Surroundings of the Alqueva Lake (PROZEA), the Plan for the Alqueva and Pedrogão dams lakes (POAAP), the Regional Plan of the Alentejo Region (PROTA) and the Projects of National Interest (PIN's), which are reflected in the recently establishment of intensive irrigated olive groves and vineyards, the construction of small marinas and golf courses and the rehabilitation of degraded farm houses into touristic resorts (Fig. 2).



Figure 2 – Construction of golf courses in the surroundings of the Alqueva dam lake.

Integrated in an area of strong population decline (-9% in the PROZEA region between 2001 and 2011 [17]), the region is planned to be promoted in terms of economic growth, employment, valorization of natural and cultural heritage and implementation of sustainable tourism programs.

PROTA defines Alqueva as a national prime touristic region to be achieved through the qualification of riverside and historic villages, construction of touristic resorts and sustainable golf courses (associated to natural spaces) and activities such as fishing and aquatic recreation [18]. More focused on the Alqueva landscape, the PROZEA plan integrates six municipalities (Alandroal, Reguengos de Monsaraz, Portel, Mourão, Moura e Barrancos), presenting a territorial proposal based on five systems: environmental protection system, agricultural and rural development system (with irrigated agriculture areas, urban and accessibility system, social system and touristic system (defining preferential areas for tourism development) [19]. The preferential areas for touristic development are integrated in urban and tourism vocational areas near the lake (POAAP, [20]). In the figure 3 it can be seen the landscape at the northern part of the

Alqueva dam reservoir just after the lake reached the maximum cote of 153 m and before to start any other land use changes.



Figure 3 -The northern part of the Alqueva reservoir in its maximum at 2010.

In terms of agriculture, the Guadiana River Plan predicts *that the trend of expansion in irrigated areas will persist towards the introduction of more intensive systems* [21], which is already happening at the present moment. The need for biomass energy is supposed to further promote agriculture. The applicable legal constraints to land use change in the area of interest are the National Agricultural Reserve (RAN), which limits the use of areas classified under this regime to agriculture and rural tourism uses; the National Ecological Reserve (REN), which limits land use change in areas of relevant ecological functions and high vulnerability, such as steep slopes, aquifer recharge areas, river or lake margins, among many other; the Natura 2000 Network, including a set of areas for biodiversity protection; and the legal protection of *Quercus ilex* L. woodlands, restraining any alteration in trees of this species (D.L. n.º 169/2001) [22].

Today, the alterations of land use continue and are expected to go on in the near future, according to the strategies defined in each of the plans above. Adding climate changes to the socio-economic drivers of change mentioned, the dynamics of land uses in the surroundings of the Alqueva dam lake can have implications on the soil properties causing erosion and potentially increasing deposition of sediment at the bottom of the lake, therefore creating the risk of silt-up before completing a 100 years period. The challenge is to predict the future land use change and landscape structure (scenarios) to assess soil loss using the RUSLE model.

4 Simulating the Future in the Alqueva Landscape: a methodology

Through MAS/LUCC, the modeling of land use change and simulation of future land use scenarios in the Alqueva landscape will be guided by the following steps:

- Creation of transition probability matrices by a cellular LUCC model. These matrices calculate land use probability of change between before and after the construction of the dam. These probabilities will be used to define change in individual land uses and to build scenarios for future landscapes. The Corine Land Cover (CLC) data from the years 1990, 2000 and 2006 will be used as input data in the process;
- Elaboration of potential transition or suitability maps to be established by MCE and AHP, with criteria of change such as the planning intentions of PROZEA, PROTA and POAAP, slope (affects differentially the location of agriculture and tourism projects), proximity of accessibilities, villages and historic elements, and constraints like RAN, REN and Protected Areas. The combination of criteria and their respective weights will define the areas more suitable to change;
- Conjugation of transition probabilities (1990-2000-2006) and suitability maps in order to allocate land uses in the landscape in 2025, 2050 and 2100;
- Scenarios validation, considering 2006 as the starting date in the simulation process, through the comparison of simulated scenarios for 2011 and satellite imagery relative to the same year (other source than Corine Land Cover).

5 Conclusion

To predict the future is a tremendous challenge. Thought the present review of the conceptual theory of MAS/LUCC methods it was possible to define a reliable methodology for the analysis and simulation of the Alqueva landscape in the future, based on land use change.

The construction of these scenarios will enable the estimation of soil erosion (using the RUSLE equation), resulting from land use and landscape configuration change. This will be done mainly through changes of vegetation cover (C factor) and maintenance or implementation of sustainable vegetation control practices (P factor). This will contribute to the prevention of silting up in the Alqueva dam lake and the safeguard of landscape sustainability.

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