Spatiotemporal analysis and scenario's simulation of agricultural land use land cover using GIS and a Markov chain model

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Abstract

In recent decades, the abandonment of agricultural land has been an international trend. In Portugal, the same occurred confirming marked changes in the agricultural landscape. With this study, we intend to identify the major changes that occurred in the agricultural areas of the largest district of Portugal - Beja - that has agriculture as economic background. Particularly, we analysed the spatiotemporal transitions of land with natural propensity or use for agricultural activities (namely, Arable land, Olive groves, Vineyards, Other permanent crops, Pastures and Heterogeneous agricultural areas) and we calculated a transition probability matrix to get a possible future scenario of the main agriculture transitions for the year of 2024, using GIS and the Markov chain model. Data from CORINE land cover for 2000, 2006 and 2012 years were used to evaluate the main changes. The analysis results show that in these 12 years, the land use type of approximately 12.9% of the territory has been changed. Despite the decrease in agricultural areas, they continue to predominate in Beja territory, occupying more than 67% of the total area. It is worth noting that Olive groves crops were the agriculture land type that increased the most between 2000 and 2012 (about 3%). Regarding the future agriculture transitions, we highlight the possible transition nearly of 13.3% among land uses between 2012 and 2024, of which the 10.5% correspond to agricultural areas. The agricultural land type that will undergo major changes is the Other Permanent crops since it has a probability of 39% to transit to other use.
Keywords: Agriculture, LULC, Spatiotemporal, CA-Markov, GIS, Beja.

1 Introduction

One of the great challenges of the XXI century is food security and enough food production to ensure the supply to the entire world population estimated at nine billion by 2050 (United Nations, 2014). According to Food and Agricultural Organization (FAO), it will be necessary to increase agricultural production by 70% to ensure the amount of food needed (FAO, 2010). However, with the continued abandonment of agricultural land and changes in land use land cover (LULC), this objective is unlikely to be feasible.

As for that, it is pertinent the identification and characterization of the spatiotemporal changes of the LULC over several periods (Campbell et al., 2005; Serra, Pons, and Saurí, 2008), to gain an overall understanding of these changes and to provide essential information for the management of these natural resources with natural aptitude or use for agricultural activities (e.g. Baessler and Klotz, 2006).

In Fuchs et al. (2014) research, about LULC modifications in Europe, stands out the increase of forest to the detriment of the agricultural land. In Portugal, the same trend has been observed, with an increase of about 3% in forestland between 1980 and 2010, due to the decrease of 5% in agricultural land between the same period (Meneses, Vale, and Reis, 2014).

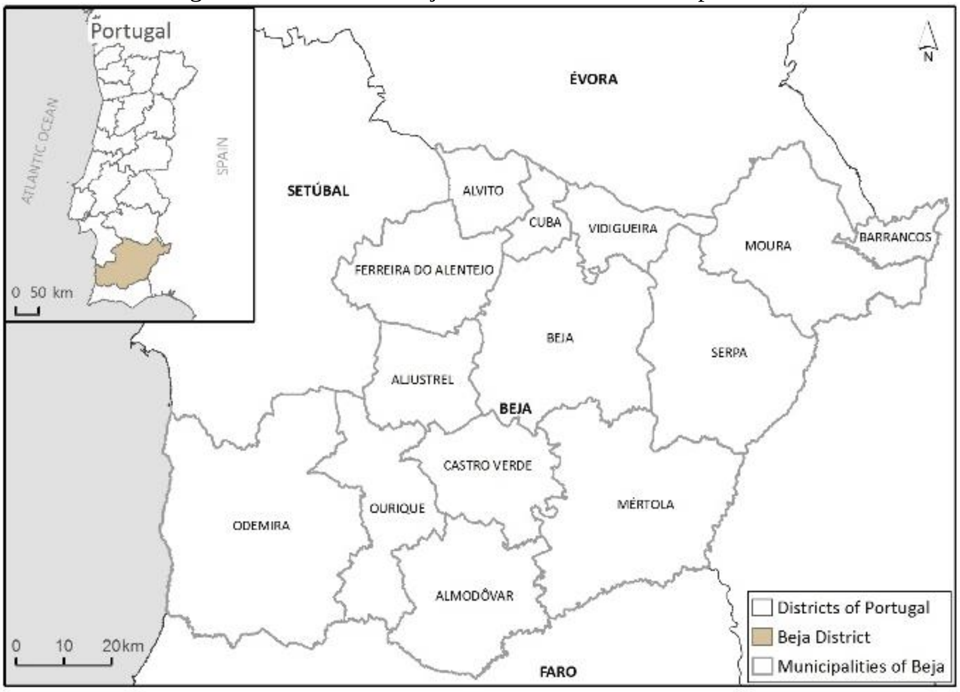
Considering the international agricultural paradigm and the marked changes in the Portuguese agricultural landscape observed in the last decades, it is urgent to monitor the dynamics of LULC at the regional level that promotes and ensures a weighted and parsimonious use of available resources. Specifically, this research intends to analyze the spatiotemporal changes of the agricultural land (namely, Arable land, Olive groves, Vineyards, Other permanent crops, Pastures and Heterogeneous agricultural areas) that occurred in Beja district, with a trend projection for the year of 2024. Being the largest Portuguese district in terms of area and the second in percentage of agricultural land, it was understood that it would be pertinent to obtain a cartographic representation and a statistical analysis of the changes that occurred between 2000 and 2012. Thus, the present study quantifies the changes of agricultural LULC in the time interval under analysis and reveals the spatiotemporal distributions of these changes. Lastly, a transition probability matrix was calculated to get a possible future scenario (the year 2024) of the main agriculture transitions.

2 Study area and data

2.1 Study Area

Located in the Alentejo egion, the district of Beja is bordered to the north by the Évora district, to the south by the Algarve region, to the east by Spain and to the west by the district of Setúbal and the Atlantic Ocean (Figure 1). Beja is the largest Portuguese district, with an area of 10,229.05 km² and a resident population of 152,758 inhabitants in 2011 (INE, 2012) distributed by the 14 municipalities that are divided by two sub-regions, Baixo-Alentejo and Alentejo Litoral. The main accident is the valley of the river Guadiana that crosses from North to South the eastern part of the district. The Alqueva dam, the largest in the country, is located in this district.

Figure 1: Location of Beja District and its Municipalities



2.2 Data

In order to understand the spatiotemporal dynamics of croplands in the Beja district, we used the Official Administrative Charter of Portugal (CAOP, version 2016) and data from CORINE land cover (CLC) for 2000, 2006 and 2012 years. The General Directorate for Territorial Development (DGT) produced both data. The CLC data structure is vector (polygons) with a minimum cartographic unit of 25 ha at a scale of 1:100 000. The hierarchical nomenclature of CLC maps has three levels of detail and 44 classes at the most disaggregated level.

The 12 years of temporal LULC changes analysis was developed considering four major classes of the first hierarchical level of the CLC nomenclature (Artificial surfaces, Agriculture, Forest, and Wetlands). In order to allow to specify the major changes in croplands and characterize the type of agricultural activity in this region, we divided the major agriculture class into six cropland use types according to the third hierarchical level of the CLC nomenclature and the empirical knowledge of the region (namely: Arable land, Olive groves, Vineyards, Other permanent crops, Pastures and Heterogeneous agricultural areas). The CLC data were clipped to the extent of the case study area, then converted to raster format and reclassified. All the cartographic information processing and statistical calculations were developed in the ESRI ArcMap 10.5.1 software.

3 Methodology

3.1 Markov-chain Model

The ability to quantify not only the states of conversion between land-use types but also the rate of conversion among the land-use types makes the Markov-Chain model able to represent the land-use change data (Iacono and Levinson et al., 2012; Basharin et al. 2004; Bayes and Raquib 2012). This model is a stochastic process (i.e., is mainly based on probabilities, not certainties) where space is discrete. The first-order Markov model assumes that to predict the state of a system at time $t + 1$, it is sufficient to know the state at time t, allowing to calculate the time index, i.e., the number of cells (area) which is expected to transit to a different type of land use.

The result of the Markov-chain model is a transition matrix, a transition areas matrix, and a conditional probability images. The first one contains the probability of each LULC type to transit to another (in the conversion process, no land is lost or created) (Eastman, 2012). The second one contains the number of pixels that are expected to transit. The third one, reports the probability that each LULC type would be found at each pixel after the specified period (Eastman, 2012). In this study, the *t* is the CLC map of 2000 and *t+1* is the CLC map of 2012 to predict the year of 2024 (interval of 12 years since this is the time difference between the two input maps). To perform the Markov-chain model we used IDRISI Taiga software.

3.2 Model agreement

In this study, we compared the number of pixels for each LULC type between the actual CLC map dated 2012 with the simulated CLC map dated 2012. To obtain the simulated CLC map we perform the Markov-chain model considering as *t* the CLC map of 2000 and *t+1* the CLC map of 2006 to predict the year of 2012 (interval of 6 years since this is the time difference between the two input maps).

4 Results and Discussion

4.1 Spatiotemporal distribution and evolution of LULC

In the first stage of the study, we conducted a spatiotemporal analysis. The results present the predominance of agricultural and forestry areas in Beja district. In Figure 2, we can verify the predominance of agricultural land in the 2000 year (70.2%, more precisely), followed by the forestland (close to 28.2%). However, between 2000 and 2012 years, there was a loss of almost 2.6% of the agricultural area, but still, this mega class continued to occupy the largest portion of the territory (about 67.6%). As for the Artificial surfaces, although much reduced in this region, they increased by 0.14% between the period under analysis. The same occurred with the Wetlands class with an increase of 0.61%.

Regarding the croplands, there was a predominance of Arable land, which are dispersed throughout a large part of these territory, despite the significant decrease in this practice between 2000 and 2012, confirming the importance of cereal production in this region, as in the case of Wheat (Agriculture in Portugal…, 2015) (Figure 3). In spite of the lesser expression in the territory, the substantial increase of Olive groves (3.3%) suggests the emphasis on intensive farming without fallow and corroborating the information available in the Portuguese agricultural statistics (Agriculture in Portugal…, 2015) that points to an increase in olive oil production between the analysis time period, proving the enlargement of the olive grove plantation in this region.

Analyzing Figure 3, we observed that, between 2000 and 2012, with less expression, there was also an increase of Pastures areas (0.38%) and Vineyards areas (0.13%). The intensification of all permanent crops types is very presumably associated with the strong exploitation of water resources, after the construction of the Alqueva dam in 2002. Specifically, in this time interval, there was a huge decrease of Arable land (5.6%) area and a slight decrease of Heterogeneous agricultural areas (0.78%). Possibly, the political measures of incentive to the increase of the technology are one of the explanatory factors for the agricultural LULC changes observed, as for example, the traditional agriculture practically total abandonment.

Figure 2: LULC changes in Beja district between 2000 and 2012 (in percentage)

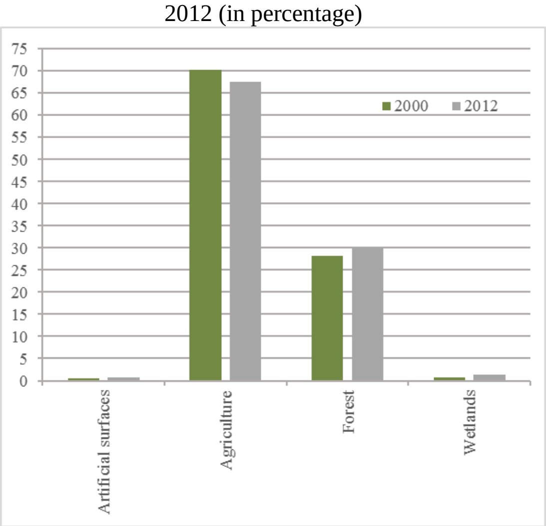
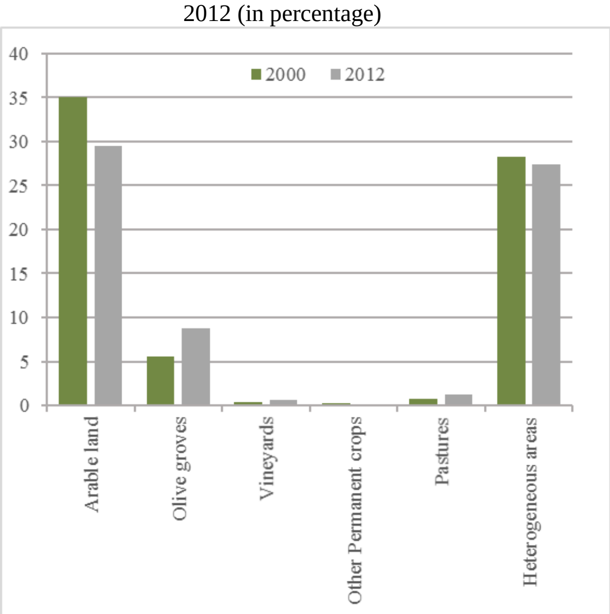
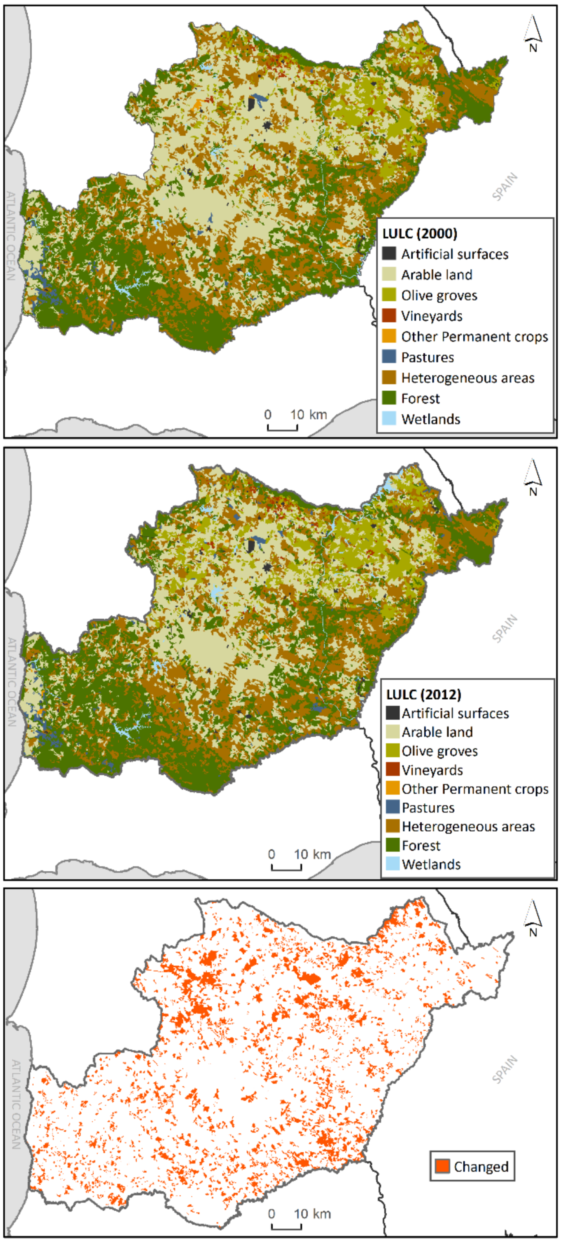


Figure 3: Agriculture LULC changes between 2000 and 2012 (in percentage)



Through figure 4, it can verify that the green patch corresponding to the forestland increased in several areas of the district. With some visible expression, highlights the increase of the Wetlands areas near the borders of the Moura and Vidigueira municipality's, due to the construction of the Alqueva dam. As for the agricultural classes, there was an expansion of the patch corresponds to the class Olive groves, particularly, in the northern part of the district. It is also noticeable the almost disappearance of Other Permanent crops class in the entire territory of Beja.

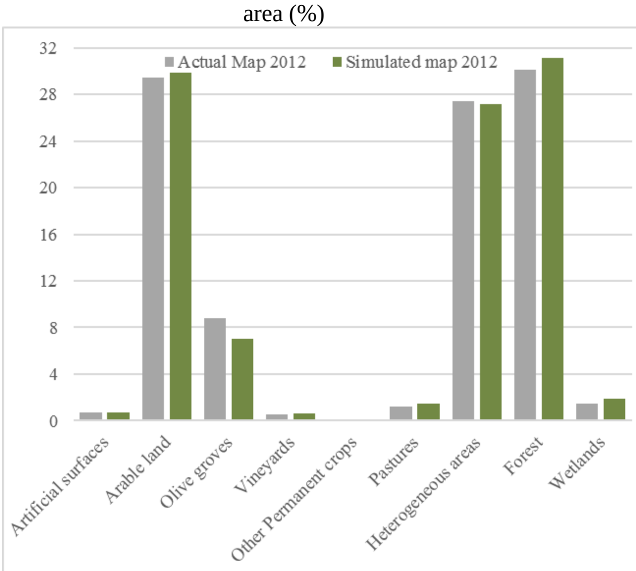
Figure 4: Spatiotemporal distribution of LULC changes between 2000 and 2012



4.2 Model agreement results

In the second stage of the study, we conducted a comparison of actual CLC map dated 2012 and the simulated CLC map for the year of 2012. The results presented a high agreement value (95.5%) between the actual map and the simulated map. Figure 5, presents the agreement of each class.

Figure 5: Model agreement for each class considering the area (%)



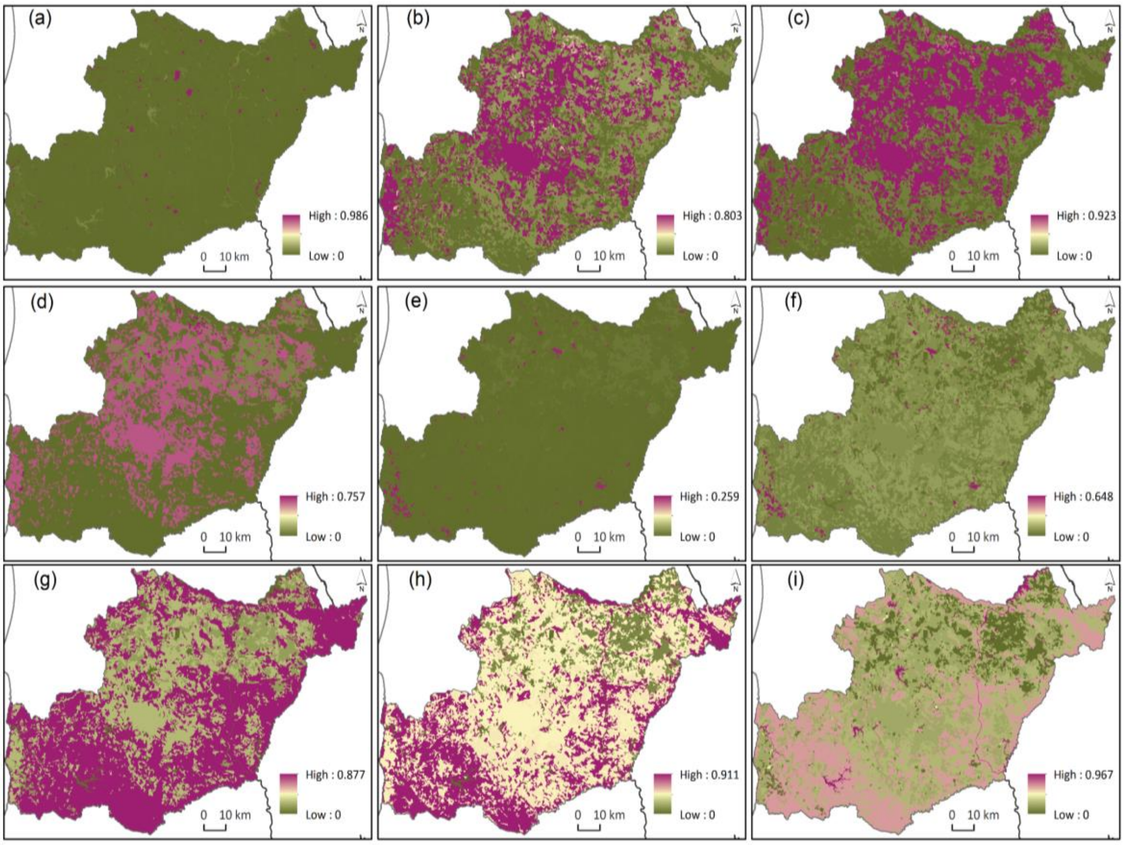
4.3 Transition matrix probability of LULC

In the third stage of the study, we performed the Markov-chain model application. Table 1, present the temporal transition-probability matrix, where the rows and columns represent LULC states and the cells represent the probability of movement between states. As expected, there is a small probability that artificial surfaces will transit for another use (1%), and the same is observed with the Wetlands areas (3%). For Forest areas, there is a probability of about 9% change in use, specifically about 7% for Homogeneous areas. With regard to croplands, there is a clear tendency for each type of agricultural use to transit for another agricultural use or to transit to forest. For example, Other Permanent crops is the class that is most likely to transit use, with a 39% probability of transit to Olive groves, 10% for Heterogeneous areas and 12% for forest areas. From all croplands, it is noteworthy the low probability of olive groves to transit use (only 8%) as well as the Heterogeneous areas (about 12%). To complement, from Figure 6, it is found the probability that each LULC type would be found at each pixel.

Table 1: Markovian transition probability matrix

Class	Artificial surfaces	Arable land	Olive groves	Vineyards	Other Permanent crops	Pastures	Heterogeneous areas	Forest	Wetlands
Artificial surfaces	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arable land	0.00	0.80	0.09	0.01	0.00	0.01	0.02	0.07	0.01
Olive groves	0.00	0.04	0.92	0.00	0.00	0.00	0.01	0.02	0.00
Vineyards	0.00	0.11	0.07	0.76	0.00	0.03	0.02	0.00	0.00
Other Permanent crops	0.01	0.11	0.39	0.01	0.26	0.00	0.10	0.12	0.01
Pastures	0.01	0.17	0.01	0.00	0.03	0.65	0.01	0.12	0.00
Heterogeneous areas	0.00	0.03	0.01	0.00	0.00	0.01	0.88	0.07	0.01
Forest	0.00	0.01	0.00	0.00	0.00	0.01	0.07	0.91	0.01
Wetlands	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.97

Figure 6: Markovian conditional probability images: (a) Probability of being Artificial surfaces, (b) Probability of being Arable land, (c) Probability of being Olive groves, (d) Probability of being Vineyards, (e) Probability of being Other permanent crops, (f) Probability of being Pastures, (g) Probability of being Heterogeneous areas, (h) Probability of being Forest, and (i) Probability of being Wetlands



5 Conclusions

The first objective of this research was to analyze the LULC changes in Beja district between 2000 and 2012. This spatiotemporal analysis allowed us to understand that in 12 years they have been significant changes in the agricultural LULC, where the 12.9% of the territory transited to a different LULC type.

The results obtained from this analysis are in line with what is happening at the national level, i.e. loss of agricultural land to the detriment of forests, as observed by the LANDYN project (DGT, 2013). This tendency may be explaining because of the abandonment of agricultural land. In spite of the decrease of this land use type, it was verified that the agricultural areas continued to prevail in more than half of the Beja district areas in the 2012 year, with the predominance of the Arable land areas that are dispersed by a great part of this territory, followed by the agricultural heterogeneous areas.

The application of Markov-chain model was the second objective of this study and allowed to understand that imbalances can arise in the future; highlighting that about 13.3% of the territory can transit use, of which about 10.5% correspond to agricultural land.

The high agreement value of this model, combined with the high applicability and flexibility provided a useful mechanism for monitoring and evaluating the LULC changes with a trend projection. However, LULC changes are complex problems and this stochastic model, that is weak in the spatial side, does not assume the influence of other variables (e.g., socioeconomic factors, climate changes, among others) in LULC changes prediction (Ye and Bai, 2008). For future works, it is recommending the combination of this model with other methods.

With this study, it was found that acquiring spatiotemporal knowledge regarding the agricultural LULC changes allowed obtaining a general picture of the main alterations of one of the regions of Portugal with more importance in the regional agricultural production sector, particularly in the production of cereals, such as Wheat, Barley, Oats, and other products such as Olive Oil. As a fact, from the various studies carried out and centered on LULC changes (e.g. Araya and Cabral, 201; Kiptala et al., 2013), there is no focus on the alterations of the different croplands, which have different characteristics and therefore, intrinsically associated with distinct agricultural practices of food production and distribution. The information obtained provides useful data for managing the use of these lands and to prepare future ecological sustainability plans.

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