APPLICATION OF STOCHASTIC PROCESS & CELLULAR AUTOMATA INTEGRATED TO GIS FOR LAND MONITORING: COASTAL CHAOUIA, MOROCCO

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ABSTRACT

In recent decades, Morocco has experienced an expansion of agriculture, industrialization and urbanization, the quality of several natural resources has deteriorated by the inconveniences of this expansion. Groundwater is among the natural resources affected by this development. This study aims to prevent groundwater pollution in one of largest degraded aquifers in Morocco, which is coastal Chaouia aquifer. The purpose of this study is to mitigate the effects of agricultural expansion and pollution from agricultural activities. Indeed, Markov process for stochastic modeling and cellular automata are integrated into GIS. As a result, forecast maps for 2011 and 2019 were developed. compatibility with projected land use maps gave a similarity rate of 89.22% for 2011 map and 82.12% for 2019 map. this great success made it possible to create a forecast map for 2027 and 2035. Analysis of land use maps classified amongst them showed that agricultural area class dominated other classes used. agricultural expansion was explained by population growth in Morocco, and in world, which requires an increase in food needs. forests were deteriorated by several causes, on one hand climate change, and on another hand agricultural practice.

Keywords: Agriculture, Cellular automata (CA), Coastal Chaouia, Forecast maps, Markov process, Morocco, Stochastic process

1. INTRODUCTION

The world has undergone a radical change in several sectors. Agriculture and agri-food are among most developed sectors, next to digital industry. This change is not random, but it is due to increased food requirements. Demographic growth is one of main causes of this evolution [1]. Morocco is one of countries that is affected by this change, its economy is mainly based on agricultural activities. Morocco has implemented reforms to develop this sector [2]. Land use change is considered an important consequence of population growth on a national and global scale [3]. Impact of agricultural development has a negative effect on environment, natural resources, and also quality of ground and surface water [4]. Climate change and irregularity of rainfall leads to overexploitation of ground water. Coastal Chaouia being on the coastal margin of 70km of Atlantic Ocean (Figure.1), it covers an area of 1120.7 km². Geographical situation between Casablanca and Settat makes this area strategically important. Indeed, this latter has a pastoral and agricultural vocation [5]. It presents an important axe in terms of agricultural production and animal production (poultry farming and livestock breeding [6]. Climate of this region is semi-arid. Main source of revenue for inhabitants is gardening [5] [7]. This activity has developed over several years using only groundwater from coastal aquifer named Chaouia. Today, its quality is in a deteriorated state, which has caused by intensive agricultural activity. Precipitation in this area is irregular. Rainfall in wet months is low and temperature is of average magnitude [2].

In view of this situation, thorough studies must be aimed at controlling and monitoring negative impact of this activity on natural resources. This paper aims to study the evolution of land use, integrating processes with GIS and based on remote sensing. Markov stochastic process and cellular automata are integrated into GIS. Landsat images of our area will be the main focus of this study.

![Figure 1](http://www.iaeme.com/IJARET/index.asp)

**Figure 1** Location Map of Coastal Chaouia [6]
2. MATERIALS & EXPERIMENTAL PROCEDURES

2.1. Methodology used in this Study

Flowchart summarizes experimental protocol used (Figure 2)

2.2. Markov chains

Markov chain model belongs to a family of random variables, which is stochastic processor. It is commonly used in engineering, biology, geographic characterization and economic [8].

A Markov chain on X of transition matrix P is a sequence of random variables (Xn) n ∈ N defined on a space (n ∈ N, B, P) and with x value in X, such that for all n, and all points x0, x

\[ \text{S}(t + 1) = P_{ij} \times S(t), \quad (1) \]

\( S(t), S(t + 1) \): State of the system at the time of t or t +1;

\( P_{ij} \): The transition probability matrix in a state that is calculated as follows [9]

\[ P_{ij} = \begin{pmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{pmatrix} \text{ with} \]

\[ 0 \leq P_{ij} < 1 \text{ and } \sum_{j=1}^{N} p_{ij} = 1, \quad (i, j = 1, 2, ..., n) \]  (2)
2.3. Cellular Automaton (CA)

Cellular automata are a particular model of discrete dynamic systems. They are used for the modeling of various natural phenomena (biology, geography…) [10]. Cellular automata have been the subject of several works in different fields [11] [12] [13] [14]. They present a set of similar cells belonging to a regular network [9].

\[ S(t, t + 1) = f(S(t), N) \]  \hspace{1cm} (3)

- \(S\): Set of limited and discrete cellular states;
- \(N\): Cellular field
- \(t\) and \(t + 1\): Different times, and rule for transforming cellular states in local space.

According to Guillaume THEYSSIER a "simulation" is a relationship expressing that behaviour of one automata is, in a way, entirely reproducible by another [10].

3. RESULTS AND DISCUSSIONS

3.1. Landsat Satellite and Classified Maps

Figure 3 shows maps obtained after treatment of satellite images. For that reason, four images were used, following years 1987, 1999, 2011 and 2019 (Table 1). Choosing these images respects clearness, availability, similar period of year, and total coverage of study area. Treatment of images has been realized by GIS software; an application of maximum likelihood classification has been applied to images.

Satellite images selected belong to Landsat satellite imagery. According to NASA, characteristics of this kind of satellite are [15]:

- Long recording due to time series analysis.
- Higher spatial resolution than other sensors with more frequent measurements
- Problem of temporal resolution that appeared due to the lack of short-term patterns.

<table>
<thead>
<tr>
<th>Sensor type</th>
<th>Acquisition date</th>
<th>Spatial resolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>LANDSAT-4 TM</td>
<td>06/01/1987</td>
<td>30m</td>
</tr>
<tr>
<td>LANDSAT-4 TM</td>
<td>07/01/1999</td>
<td>30m</td>
</tr>
<tr>
<td>LANDSAT-4 TM</td>
<td>08/01/2011</td>
<td>30m</td>
</tr>
<tr>
<td>LANDSAT-8 OLI/TIRS</td>
<td>18/01/2019</td>
<td>30m</td>
</tr>
<tr>
<td>DATA OF DIGITAL ELEVATION MODEL (DEM)</td>
<td>2019</td>
<td>30m</td>
</tr>
</tbody>
</table>

Table 1: Kinds of satellite imagery used
3.2. Amount Change in Area of Land Cover over 32 years in Square Kilometer

Graph 1 analysis has allowed to state the following points:

- **Water area:** Water area has undergone a very small change. In 1987, water surface covered 24.5 km². A decreasing water area was observed in 2011, with a slight increase in 2019 (22.7 km²);
- **Forest area:** In 1987, soil occupied by forests reached 569.3 km². A considerable loss of area was recorded in 2011 (17.9 km²). A slight increase was observed in 2019 (68.2 km²);
- **Farmland area:** Rate of agricultural land has increased rapidly between 1987 and 2019. Amount of change has peaked to 695.9 km² in 2019;
- **Building area:** Area occupied by buildings has increased slightly, from 42.9 km² in 1987 to 107.7 km² at present.
- **Bare ground area:** In this category, an irregularity of quantity occupied by bare ground has been noticed for 32 years. This latter can be explained by ploughed land, which was considered bare ground during supervised classification, in fact, low resolution of satellite imagery used doesn’t allow this distinction.

Figure 3 Land use maps [6]: (a) 1987; (b) 1999; (c) 2011; (d) 2019
3.3. Validation of Model for Predicting Land use Changes

Kappa index was used to validate results obtained. Comparison is made between simulated map of 2011 and map obtained from supervised classification of Landsat satellite imagery of 2011. Similar operation is applied to land use map of 2019. Number of iterations which allowed to obtain these simulated maps, is the 7th iteration. In this latter validation gave an optimal similarity value. Validation rate is presented as follows:

- For 2011: 89.22% for Kstandard, 91.4% for and 92.35% for Kno;
- For 2019: 82.12% kstandard, 86.29% for Klocation and 86.83% for Kno.

Spatial repair of these maps has allowed scientists to detect concordance between maps. The main objective of this method (kappa index) is to produce predictive maps over next decades. In fact, the success of this approach influences on precision of data provided by predicted land-use maps. Consequently, this latter serves to help decision-makers based on reliable results, and will therefore reduce the rate of failure in initiatives taken by stakeholders.

3.4. Current and Predicted Maps of Land use Change

Combination of Markov chain with cellular automata (CA), has made it possible to develop forecast maps (2027 and 2035) (Figure 4), based on classified maps of 1987, 1999, 2011 and 2019 (Figure 3). the latter have permitted to assess and observe land use change. Remote sensing and GIS have made land use monitoring easy. The predicted maps make decision-making by planners and stakeholders for environmental conservation becomes very clear. Indeed, decision-makers will measure with a very high degree of certainty the impact of agricultural expansion on natural resources in this study area. Simulation by CA-Markov model has been successful. Indeed, dynamic spatio-temporal models of land use change have been realized in Coastal Chaouia.
4. CONCLUSION

In recent decades, demand for food has grown significantly, to meet increased population needs. Indeed, agricultural development has become increasingly important. Consequently, negative effects on environment, natural resources and also on the quality of ground and surface water have been identified. In this context, the present study has been carried out to study the evolution of land use in coastal Chaouia, integrating Markov process for stochastic modeling and cellular automata into GIS. Satellite images were of great importance for our study.

The combination of Markov chain with cellular automata (CA) allowed the development of prediction maps (2027 and 2035), which were based on classified maps of 1987, 1999, 2011 and 2019. These maps were used to assess and observe land-use changes. The resulting maps will allow decision makers and planners to measure with a very high degree of certainty the impact of agricultural expansion on natural resources in the study area. As a result, proper management with integration of sustainable development will be achieved.

REFERENCES


