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Spatiotemporal Monitoring and Prediction of Land Use Integrating the Markov Chain and Cellular Automata in the Coastal Chaouia

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Abstract: *In the last decades, the world population rate has been gradually increasing, this population growth has faced intense urban expansion and the rapid development of the agricultural and industrial sectors. This change had an impact on the mode of land use. In the face of this problem, several strategies have been created for monitoring and predicting possible future scenarios on rhythm of land use change. The CA-Markov model used in this research allows to predict future land use trends on the basis of the classified maps of 1987, 1999, 2011 and 2019. Simulating and tracking these maps is a major challenge. The latter provides important information in terms of data, methods and models to be used to create a realistic and sustainable process of territory planning for environmentalists, planners and local authorities. The combination of the Markov chain and cellular automata has been used to qualitatively and quantitatively simulate and evaluate future land use trends in coastal Chaouia, Morocco. To achieve this purpose, two maps were developed for the two years of 2027 and 2035. By using kappa, the global success of the modelling was 89.22% and 82.12% respectively in 2011 and 2019 for the projected land use map. The results confirm that forests have been affected by intensive agricultural uses. This increase in agricultural use is due to the impact of the constant increase in the development of the agroeconomic and demographic sectors. This situation indicates the need to create new approach to management to protect the sustainability of land use in coastal Chaouia.*

Keywords *: Coastal Chaouia , CA-Markov, kappa, Markov chain, cellular automat(CA).*

I. INTRODUCTION

The main consequence of the world population rate increase has been the rapid change in land use which has caused the urban expansion and the development of industrial and agricultural sectors. This latter has faced various worldwide environmental problems such as climate change, air and water pollution [1] [2]. In order to effectively monitor and track land use changes, it is of paramount importance to develop planning tools which will allow us to predict the

future evolution of the urbanization and the agricultural expansion. The use of remote sensing has provided new data on land use and cover [3] [4] [5] [6]. In this context, a combination of cellular automata (CA), the Markov chain and the Geographic Information System (GIS) has been used in the simulation model for land use [7]. Cellular automata (CA) and the Markov model have great advantages for studying land use change. The Markov model has been widely used for land use change, but with the traditional Markov model, it is difficult to predict the spatial model of land use change [8]. On the other hand, the CA model with powerful spatial computation has been used to effectively simulate the spatial variation of the system. But, CA - Markov model presents a robust approach to the dynamic spatiotemporal modelling of land use since geographic information systems (GIS) and remote sensing are well integrated [9] .

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II. METHODOLOGY

A. Area study

The Coastal Chaouia covers an area of 1120.7 km², between the cities of Casablanca and Azemmour (Fig1); it presents an important axe of Casablanca-Settat region in terms of agricultural production on one hand (beet, cereal, legumes, market gardening...), and animal production on the other hand (livestock breeding and poultry farming). The coastal Chaouia aquifer is an important groundwater reservoir in this region, but its quality is currently in a deteriorated state. Indeed, strong agricultural and agroindustry activities have led to an overexploitation of water resources and caused various pollution problems, mainly by pesticides and fertilizers, as well as water salinity through intense drainage for irrigation and industrial use.

B. Methods and Materials

In this study, four satellite images (Table 1) were selected. The choice of these images is based on the availability of the images during the month of January and the total coverage of the study area.

The maximum likelihood classification method was applied to these images, which were classified by selecting specific polygons. Five classes were used, namely water, forest, farmland, building and bare ground class.

The approaches adopted in this work are those of MARKOV, CA-MARKOV and VALIDATE, which were used to model and project the land use change for the Coastal Chaouia Groundwater. First, the classified images of 1987 and 1999 form the base maps; so these were integrated into the Markov chain processing to provide data on the transition of probability matrix and area matrix. The transition probability matrix is the product of the cross tabulation of the two images (1987 and 1999) adjusted by the proportional error. The transition area matrix is the result of multiplying each column of the transition probability matrix by the number of corresponding land use cells in the last image. The results of the MARKOV treatment were treated with the CA Markov model for a second time, by choosing the default value 5*5 for cellular automata and changing the number of iterations each time (in our case the iterations used are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 20, 30, 40, 50, 60, 70, 80, 90, 100). The results of this method are forecast maps for 2011. The validation of the method was done by calculating the kappa index, this step is based on the comparison between the 2011 real map with the simulated maps of the same year. The selected prediction map is the map closest to the actual map, i.e. the one with a higher standard kappa index. Similarly, the 1999, 2011 and 2019 maps underwent the same previous steps, Figure 2 summarizes the method used in this work.

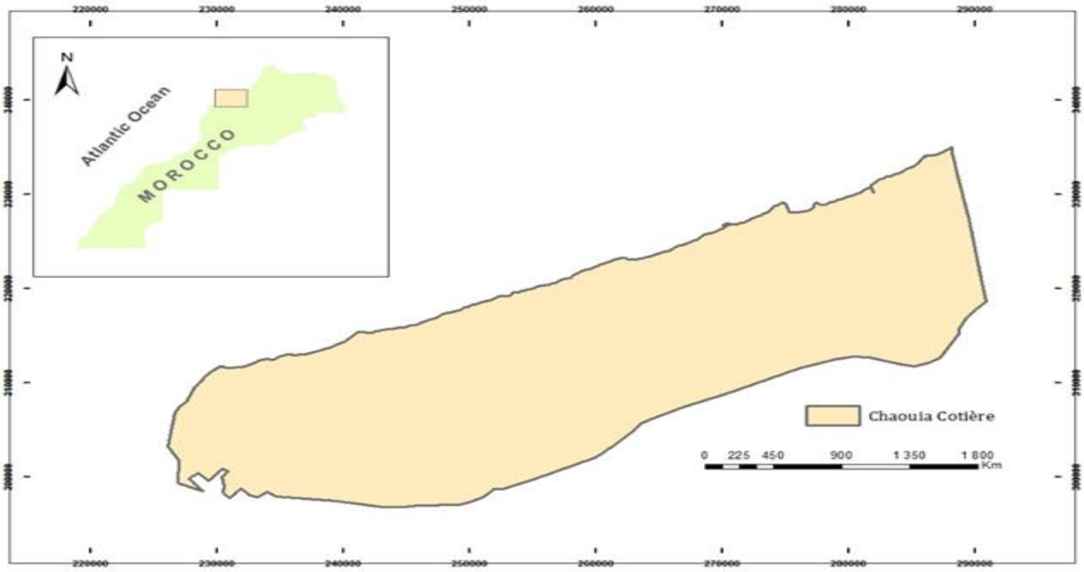

Fig. 1. Study Area location Map

C. Methods and Materials

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Table- I: Satellite imagery used

Sensor type	Acquisition date	Spatial resolution
Landsat4-5tm	06-01-1987	30m
Landsat4-5tm	07-01-1999	30m
Landsat4-5tm	08-01-2011	30m
Landsat-8 oli/tirs	18-01-2019	30m

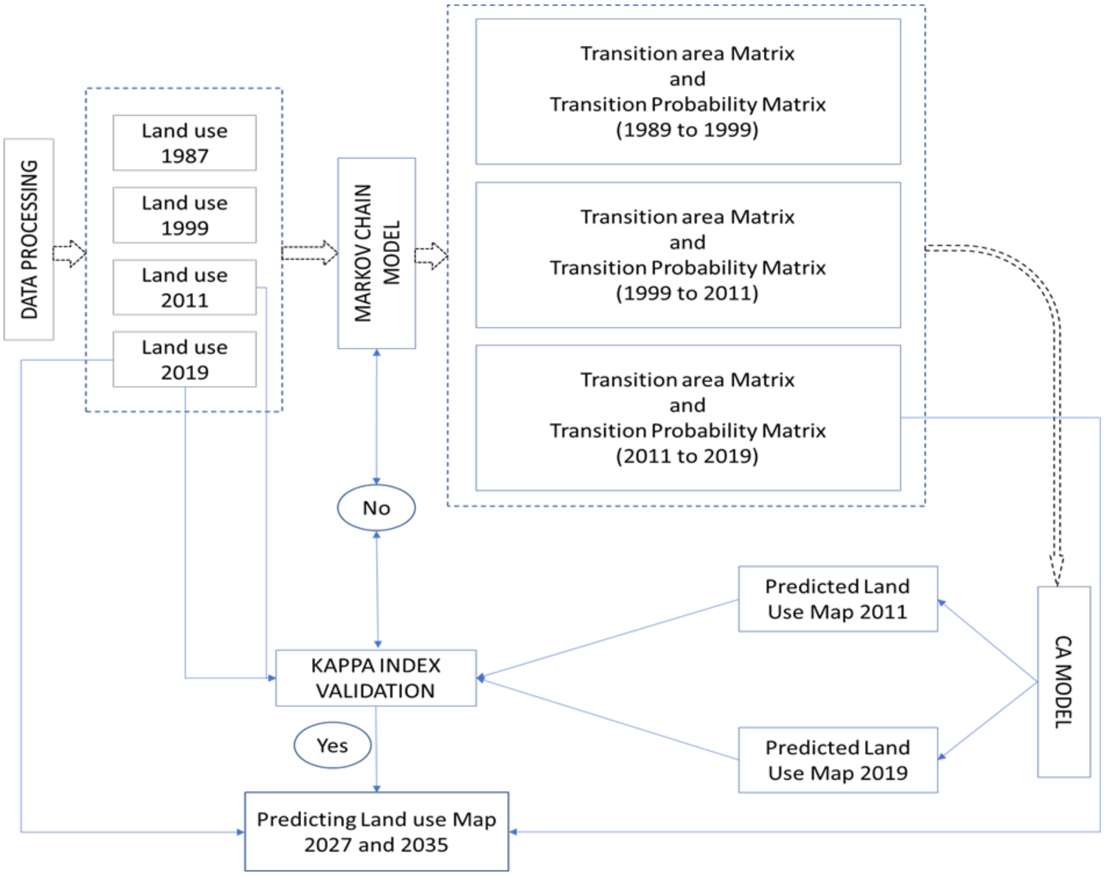


Fig. 2. Flowchart of the method used (CA-Markov Model)

D. Markovchains

The Markov chain model is a theory based on the process of the formation of Markov stochastic process systems, for the prediction of a state being changed to another state, Its essential principle takes account of the evolution of past states to predict how a particular variable has changed with time.[10]. The Markov model is frequently used in the prediction of geographical characteristics without secondary effects which has become an important prediction method in geographical research [8].

The applicability of Markov's model to land-use change modelling is promising because of its ability to quantify not only the conversion states between land use types, but also the conversion rate between land use types [10]. The prediction of future land use changes can be calculated as follows based on a conditional probability formula using the following [11]:

$$S(t+1) = Pij \times S(t), \qquad (1)$$

Where *S(t)*, *S(t +1)* are the state of the system at the time of *t* or *t +1*; *Pij* is the transition probability matrix in a state that is calculated as follows [11]:

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

$$\left(0 \le P_{ij} < 1 \text{ and } \sum_{j=1}^{N} P_{ij} = 1, \ (i,j = 1,2,\dots\ n)\right) \ (2)$$

E. CA and CA- markovchains

The principle of the cellular automaton consists in taking into account the state of cells neighbouring that considered in the definition of its future state. We thus obtain a spatiotemporal Markov chain that therefore takes into account a spatial correlation that expresses the dependence of a cell's future state on the state of its neighbours, and a temporal correlation or the future state of a cell depends on its previous state.

The spatial correlation can be uniform, it is introduced into the simulation as a filter that modifies the content of a cell in the PLC according to these neighbours. However, the latter does not account for exogenous determinants of spatial correlation, such as discontinuous breaks (slope, road, parcel...) that modify the degree of binding between the determining cells, which are generally very important and known to data users [12] [11]. The model of cellular automata is expressed by the following equation [11]:

$$S(t, t+1) = f(S(t), N), \qquad (3)$$

where S is the set of limited and discrete cellular states, N is the cellular field, t and t + 1 indicate the different times, and f is the rule for transforming cellular states in local space.

The CA-Markov model is the result of the combination between cellular automatons and the Markov chain, whose purpose is to introduce special elements to temporal elements. Indeed, the Markov chain manages the temporal dynamics between use categories in relation to land cover, according to transition probabilities, while spatial dynamics is controlled by local rules determined by the CA spatial filter or by transition potential maps [14] [5].

III. RESULTS AND DISCUSSION

A. Amount of land use changes observed in square kilometers

The results of the analysis of land use change are presented in Table 2. During the period 1987-1999, about 45.4 km² of forests and 0.1 km² of water were transformed into 28 km² agricultural areas, 0.9km² into buildings and 17.4 km2 into bare soil. Between the period 1999-2011 we notice that there is a transfer of 12km² of bare soil and 0.5 km² of forests in 9 km² of agricultural land, 2.9 km² in buildings and 0.6 km² in ater, In addition, between 2011-2019 the bare land is transferred to agricultural land with an area of 10.3 km² followed by forests 6.3km², buildings 2.3km² and water 0.3km². The total loss of forest area during these 32 years reaches almost 501.1 km², which has been transformed mainly to agricultural areas by an area of 526.7 km², which is considered as a very significant land-use change over a short period of time. In addition, the surface area of the buildings itself increased by 64.8 km², followed by a decrease of 88.6 km² in the surface area of the bare ground. However, this remarkable rate of land use change from forest to agricultural and urban areas raises many questions about agricultural growth patterns in the Chaouia Coastal area, the overexploitation of water resources, as well as the intense degradation of the quality of the waters of the coastal Chaouïa aquifer and the salinity of the fresh water of the aquifer, in addition to the sustainable environmental policies and regulations monitored and applied in the study area.

	Water area	Forest area	Farmland area	Building area	Bare ground area
1987	24.5	569.3	169.2	42.9	314.8
1999	12.9	24.3	505.6	54.2	523.8
2011	20.4	17.9	613.5	89.2	379.7
2019	22.7	68.2	695.9	107.7	226.2
Annual change 1987-1999	-1.0	-45.4	28.0	0.9	17.4
Annual change 1999-2011	0.6	-0.5	9.0	2.9	-12.0
Annual change 2011-2019	0.3	6.3	10.3	2.3	-19.2
Total change	-1.8	-501.1	526.7	64.8	-88.6

Table- II: Amount of land use changes observed in square kilometers

B. Matrices of land use change and transition probabilities

The transition probability matrices were calculated using Markov chain analysis. Table 3 illustrates these transition probability matrices by giving the likely future percentages of land use change over the 1987-1999, 1999-2011 and 2011-2019 periods. However, reading Table 3 allows us to see that the probability of a future change from forest land to agricultural areas between 1987-1999 is 50.41%, This transfer of forests to agricultural areas persisted between 1999-2011, when the probability of change reaches 30.88%, however between 2011-2019, the percentage probability of change from forest land to agricultural areas decreased compared to the other periods, it took as value 7.44%. Therefore, the large difference between these probabilities reflects the alarming and dramatic decrease in forest land in the Coastal Chaouia. On the other hand, the future evolution of agricultural areas towards forest areas is very low, ranging from 0.66% in 1999, 0.72% in 2011 and a further increase of 5.38% in 2019, this increase is explained by state efforts through the national programme to combat desertification and the annual programmes for reforestation and forest regeneration.

Table- III : Transition probabilities matrices of periods: 1987–1999, 1999–2011 and

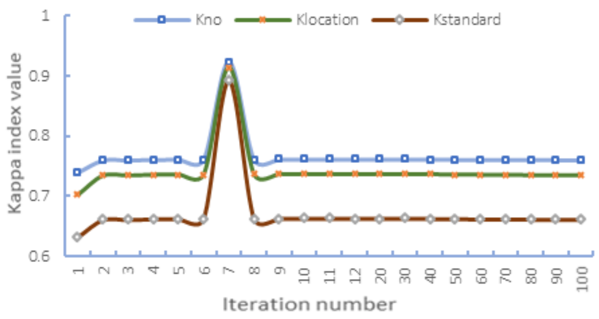
2011–2019

		Water	Forest	Farmland	Building	Bare Ground
1987-1999	**Water**	**0.4398**	0.0003	0.0013	**0.5530**	0.0057
	Forest	0.0001	**0.0328**	0.5041	0.0197	0.4434
	Farmland	0	0.0066	**0.5224**	0.0234	0.4475
	Building	0.0044	0.0044	0.1888	0.4377	0.3648
	Bare Ground	0	0.0050	0.4356	0.0243	**0.5350**
1999-2011	**Water**	**0.7295**	0	0.0036	0.1353	0.1317
	Forest	0.0008	**0.4880**	0.3088	0.0660	0.1365
	Farmland	0.0002	0.0072	0.5511	0.0547	**0.3868**
	Building	0.2007	0.0010	0.1521	**0.5005**	0.1458
	Bare Ground	0.0006	0.0023	**0.5756**	0.0705	0.3511
2011-2019	**Water**	**0.9326**	0	0.0157	0.0488	0.0028
	Forest	0	**0.8352**	0.0744	0.0285	0.0618
	Farmland	0	0.0538	**0.7324**	0.0506	0.1631
	Building	0.025	0.0056	0.1749	**0.6308**	0.1637
	Bare Ground	0.0036	0.0521	0.6064	0.0464	**0.2915**

C. Validation of the model for predicting future land use changes

In order to make a validated forecast of future land use models, the CA-Markov model was applied to predict the state of land use in 2011 and 2019, and to ensure the reliability and validation of the model, the projected land use maps for 2011 and 2019 were compared with the actual maps using Kappa index statistics to verify the validity in terms of quantity and use. Graphs (a) and (b) in Fig 3 show the variation of the kappa index as a function of the change in the number of iterations. The two models have an optimal value at 7 iterations, citing a standard Kappa index (Kstandard) of 0.8922, a Kappa location index (Klocation) of 0.914 and a no Kappa index (Kno) of 0.9235, in 2011; in 2019 a Kstandard of 0.8212, Klocation of 0.8629 and Kno of 0.8683. The results obtained provide a very good match between the actual and projected maps.

(a)



(b)

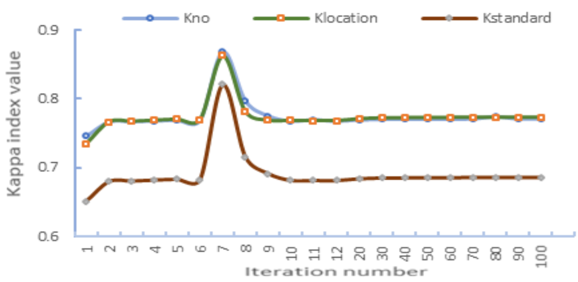


Fig 3: Kappa indices values vs number of iterations: (a) 2011, (b) 2019

D. Quantity of previous and predicted land use change in square kilometers

Following the validation phase, the results obtained led to the development of the planned land use maps for 2027 and 2035 (Fig4). Over the next decade, the CA-Markov simulation predicted that agricultural land would increase from 695.89 km2 in 2019 to 671.39 km2 in 2027 and 644.64 km2 in 2035 in the Chaouia Coastal region (Fig 5). Then there will be a regression in agricultural areas accompanied by the regeneration of forests (from 68.22 km² in 2019 to 106.86 km² in 2027 and 143.19 km² in 2035), indeed, agricultural areas would be occupied by urban and forest areas. In addition, future land use change scenarios show that there will be effective programmes to combat desertification and regional development in the Coastal Chaouia. The CA-Markov model used in this research predicted future land use trends. This important information is very useful for environmentalists, planners and decision-makers. The study of these results found that land use changes the rate, behaviour and rate of change, but these forecasts are based on limited data, without taking into account biophysical and anthropogenic factors.

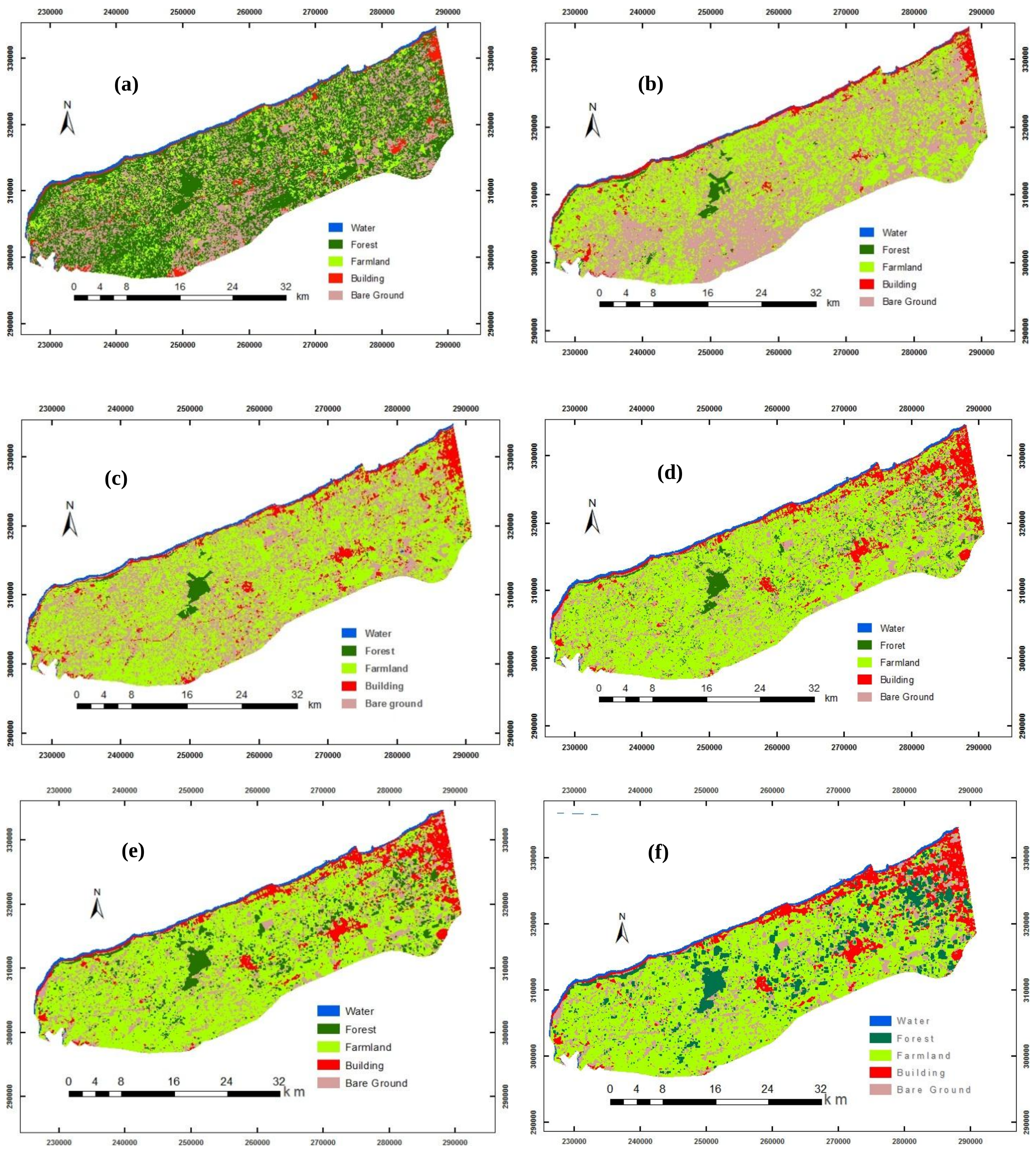


Fig.4. Land use maps in different years: (a) 1987, (b) 1999, (c) 2011, (d) 2019, (e) 2027, (f) 2035

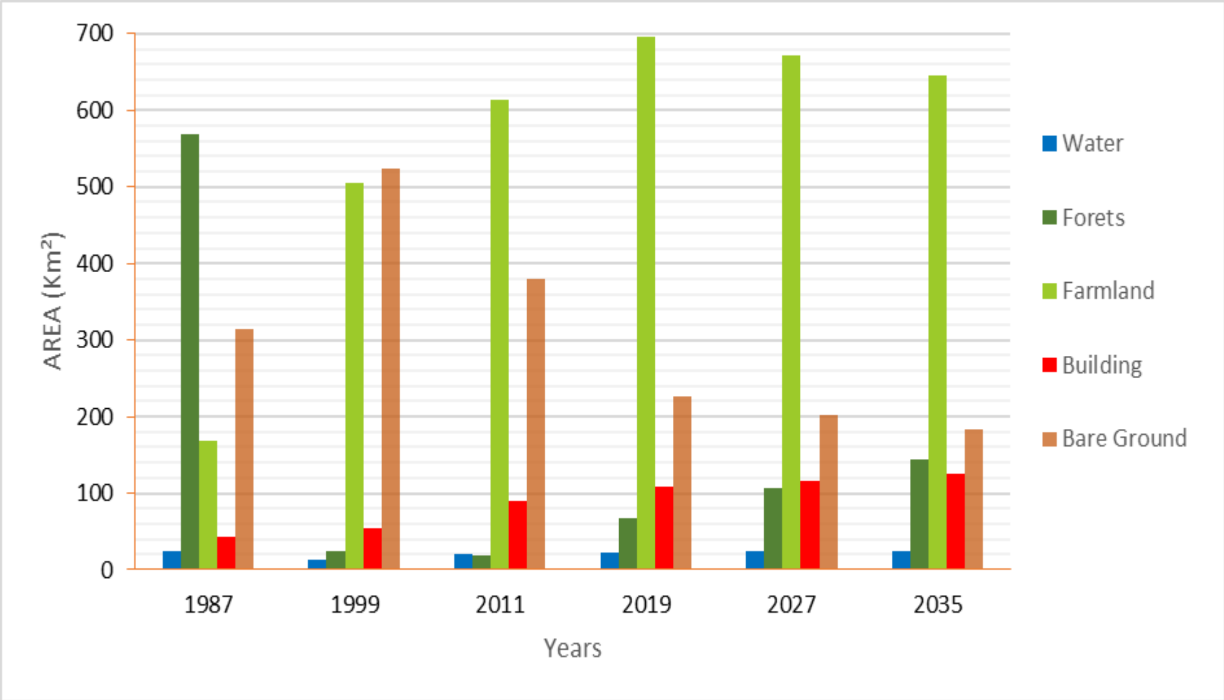


Fig.5. Quantity of previous and predicted land use change in square kilometers

IV. CONCLUSION

This study has effectively identified, analyzed and simulated future land use trends at the coastal chaouia using data from 1987 to 2035. The results of the classified maps confirm that forests have been affected by intensive agricultural uses. This increase in agricultural use is due to the impact of increased agro-economic and demographic development. The rapid development of agricultural areas in the Coastal Chaouia, leads to the deterioration of forests, this change affects ecosystems through intense water pollution. The combination of the Markov chain with cellular automata (CA) has resulted in the development of predicted maps from classified land use maps, the CA-Markov model has successfully simulated dynamic spatio-temporal models of land use change at Chaouia Coastal, with very high kappa standard indices, 89.22% and 82.12% of success respectively in 2011 and 2019. The predicted maps have shown that in the coming decades, forests are regenerating and the urban area will expand by replacing the agricultural area. In addition, future land use change scenarios show that there will be effective programmes to combat desertification and regional development in the Coastal Chaouia. The study of these results has shown that land use changes the rate, behaviour and rate of change, but these predictions are based on limited data, without taking into account biophysical and anthropogenic factors; hence, the need to integrate a new classification model to improve accuracy and performance based on topographic factors (slope, altitude, etc.) and their weights.

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