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MONITORING AND FORECASTING LAND USE CHANGES AND URBAN GROWTH USING MARKOVIAN CELLULAR AUTOMATA SPATIAL MODEL – CASE STUDY: MARSA MATROUH CITY, EGYPT

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Abstract

The objective of this paper is to establish a framework that quantifies land use changes and forecasts urban growth trends. Satellite imageries with moderate resolution (Landsat TM 5 and 7) are used to study the changes in land cover and land uses over a 15 years period (1987 to 2002). Two land use/land cover maps are produced for the two dates, then processed using a two steps Markovian Cellular Automata model. To enhance the projected land use of 2006, socioeconomic preferences and anthropogenic factors are collected and mapped using a raster/vector hybrid geographic information system. The anthropogenic factors are identified and weighted by a selected group of stakeholders. Finally, these factors are mapped and presented in raster form. The final projection of land use and urban growth is assessed both spatially and quantitatively. The spatial assessment is achieved by comparing the projection land use for 2006 against a spatial high resolution image (IKONOS MS) of the same area and date. Quantitative assessment of the model is achieved by creating an error matrix that compares the results of the projected land use to the actual land use depicted in the high resolution image. The accuracy assessment demonstrated an accuracy of 69.5%, which is considered acceptable in the modeling of land use changes using Landsat imageries.

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INTRODUCTION

The population growth and the unbalanced spatial distribution of this growth on land is a serious problem in Egypt. The population of Egypt increased from 17 million in 1956 to 74.9 million in 2006. With a 1.87% growth rate, Egypt's population is expected to exceed 185 million in 2050 (CAPMAS, 2006). In order to alleviate population pressure from the Nile Delta and Valley, the quest to direct urban growth to new desert areas has been the cornerstone of Egyptian policy. The Government of Egypt responded to this urban challenge by initiating several spatial and strategic planning projects that attempt to direct urban growth in desert areas, to create a better living environment and to protect valuable land and water resources (Abul-Azm, Abdel-Gelil, & Ivicia, 2003), (Klaric, et al., 1999), (El-Raey, El-Bastawissi, Nasr, Abdrabo, El-Hattab, & Mohammed, 1999) and (NWCID, 2003). In most cases those projects didn't completely achieve their objectives because of the absence of a future vision for the land use distribution that is based on the study of land use patterns and the prediction of the future trends based on anthropogenic preferences and demands.

Land use forecasting can assist planners and decision makers to foresee impacts of their policies and actions which provide for them the chance to enhance their plans (Wegener, 1994). To date, various land use forecasting models were developed - especially in the field of urban land use purposes. Most of these models are reviewed by Schock (2000) and EPA (2000). The objective of this research is to present a combined GIS and remote sensing framework for land use forecasting using a Markovian Cellular Automata spatial model enhanced by a set of socioeconomic data and anthropogenic factors. This model is used to predict the future land use trends and expected urban growth in Marsa Matrouh city and its vicinity using available historical remotely sensed data.

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Study Area

Marsa Matrouh city is the capital of Matrouh Governorate. It is located 300 km west of Alexandria on the Egyptian north western coast of the Mediterranean Sea, and extends from east to west as a crescent shape surrounding the Matrouh bay. The city is located between 27º 10` 14.5``E and 27º 20` 24.6``E, and 31º 18` 13.4``N and 31º 22` 44.6``N as shown in figure 1. According to the census data, the total population of Marsa Matrouh is 113,413 inhabitants in 2005 and it is expected to exceed 200,000 by 2015. The main socioeconomic activities in the area are agriculture, grazing and urban services (IDSC, 2006).

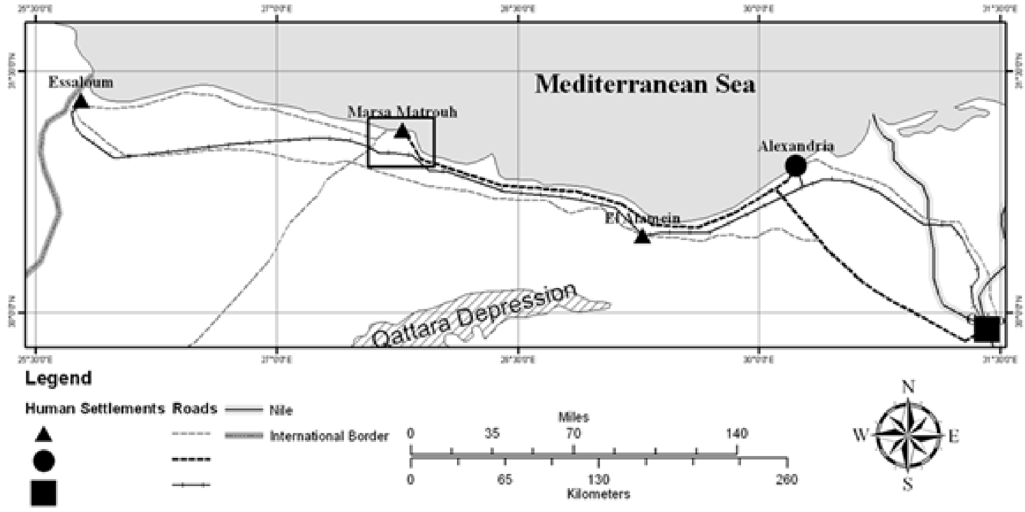

Figure 1 : Location of Marsa Matrouh City in the North Western Coast of Egypt. Title.

RESEARCH METHODOLOGY

The framework of this study is composed of three phases as shown in figure 2. The objective of phase one is to produce land cover / land use maps using classic statistical classification process for satellite multispectral dataset in two dates. In phase two, the land use maps are used to model land use dynamics quantitatively using Markov chain analysis. Inverse Markov chain analysis is adopted to produce projected land use map. The purpose of the final phase is to enhance the projected land use map. Three sets of anthropogenic factors presenting local community opinion and experience are used to create a suitability map. Cellular Automata is finally used to combine the three suitability maps and to enhance the projected land use model.

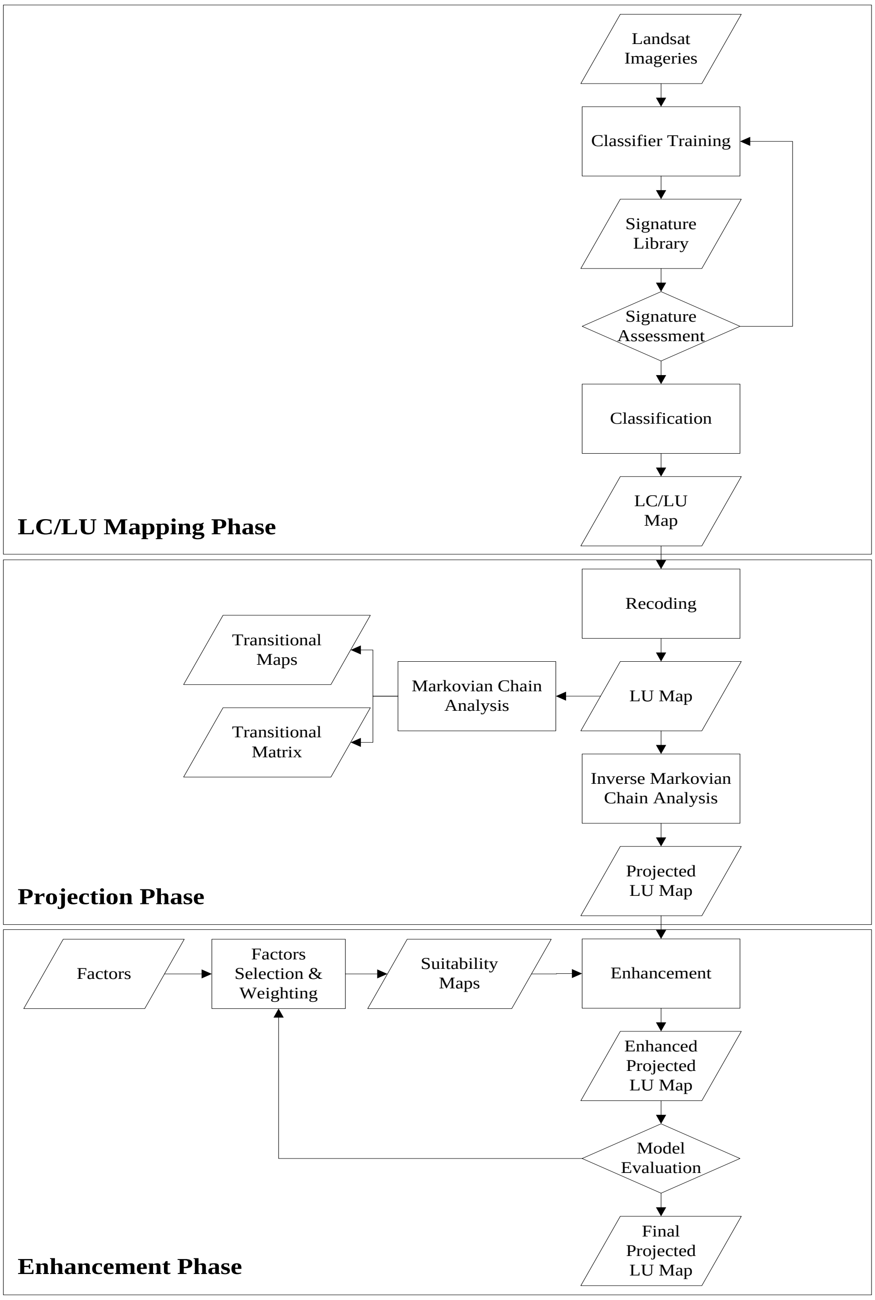

Figure 2 : Methodological Framework.

Data used

Two Landsat images are used to map and detect land cover / use changes during the period from 1987 to 2002. The first image was produced by a TM 5 sensor in 9 February 1987 and the second by an ETM sensor in 27 May 2002. Both images are cloud free and georeferenced to UTM Zone 35N Projection / WGS 1984 Datum (figure 3a,b). In addition, three datasets are used as reference data to acquire the training sites needed to carry out the classification process: Matrouh land cover map produced by Matrouh Resource Administration in 1988, two general purpose maps of 1:50,000 produced by the Egyptian Military Survey Administration in 1999 and the Atlas of North West Coast and Inland produced by NWCID project (NWCID, 2003).

Land Cover / Land Use Mapping

The land cover and land use classification system for Egyptian arid and semi arid coastal areas developed by Mohammed, Elkaffass, & El Raey (2000) is used to describe land cover classes in the study area as depicted in table 1.

Land Cover Class	Description
Water	Permanent water bodies.
Urban	Residential, industrial, services, commercial, transportation and the other mixed urban land use.
Urban / Rural Fringes	Areas landscaped and prepared to future urban land use.
Vegetation	Crops, orchards and gardens.
Grass Land	Natural herbaceous rangeland, salt marshes, shrubs and brush rangeland.
Rocky Land	Barren rocks, strip mines, and gravel pits.
Extraction	Beaches, sand, sand stones, quarries and other sandy areas.

Table 1: Land Cover / Land Use Classification Scheme for Egyptian Arid and Semi Arid Coastal Area.

To identify the training sites for the 2002 ETM subscene, 126 training sample polygons are selected to represent different classification scheme. These polygons include 16979 pixels, accounting for approximately 2.8 % of the total subscene pixels. For the 1987 TM5 subscene, 299 polygons (40365 pixels) are selected, covering approximately 2.1 % of the total subscene pixels. The minimum and maximum sizes of the training sample polygons are 100 and 300 pixels respectively. A signatures library is developed using the identified training sites. Signatures are evaluated using contingency matrix and Jefferies–Matusita distance measurements for separability. Both the signatures library and the subscenes are processed using a maximum likelihood supervised classifier to produce land cover maps that describe 1987 and 2000 land cover distributions (figure 4a,b).

In order to estimate the classification accuracy, a stratified random technique is adopted. The final number of points used in the actual assessment for the 1987 and 2002 subscenes are 75 and 96 respectively. The error matrix is then calculated by comparing the location and class of each reference data pixel with the corresponding location and class in the classification image. The overall accuracy for the 1987 classification is 96.00%, and for the 2002 classification is 96.88%, while the Kappa statistics are estimated to be 0.953 and 0.963 for the 1987 and 2002 classifications respectively. Error matrix is shown in table 2.

Land Use Dynamics Modeling and Projection

Modeling land use dynamics is based in this paper on a Markovian chain analysis, which considers that the land use in a later date can be predicted by the state of land use in the earlier date, given a matrix of transition probabilities from each land use class to every other land use class. The dynamics of land use transitions are described in the context of a Markovian analysis by three items (Luijten, 2003):

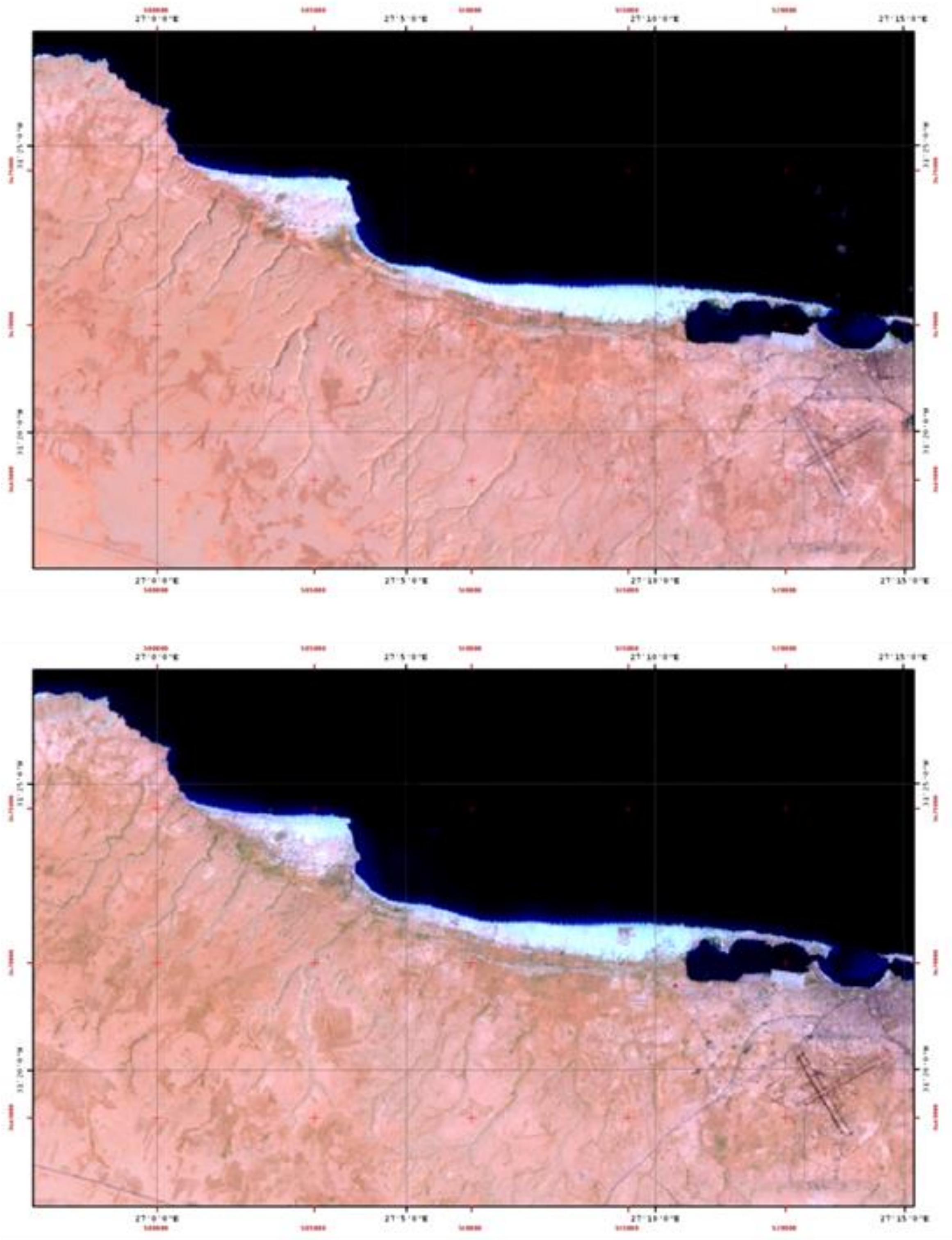

Figure 3 : : Landsat 5 TM Subscene for the study area: (a) 1987, (b) 2002.

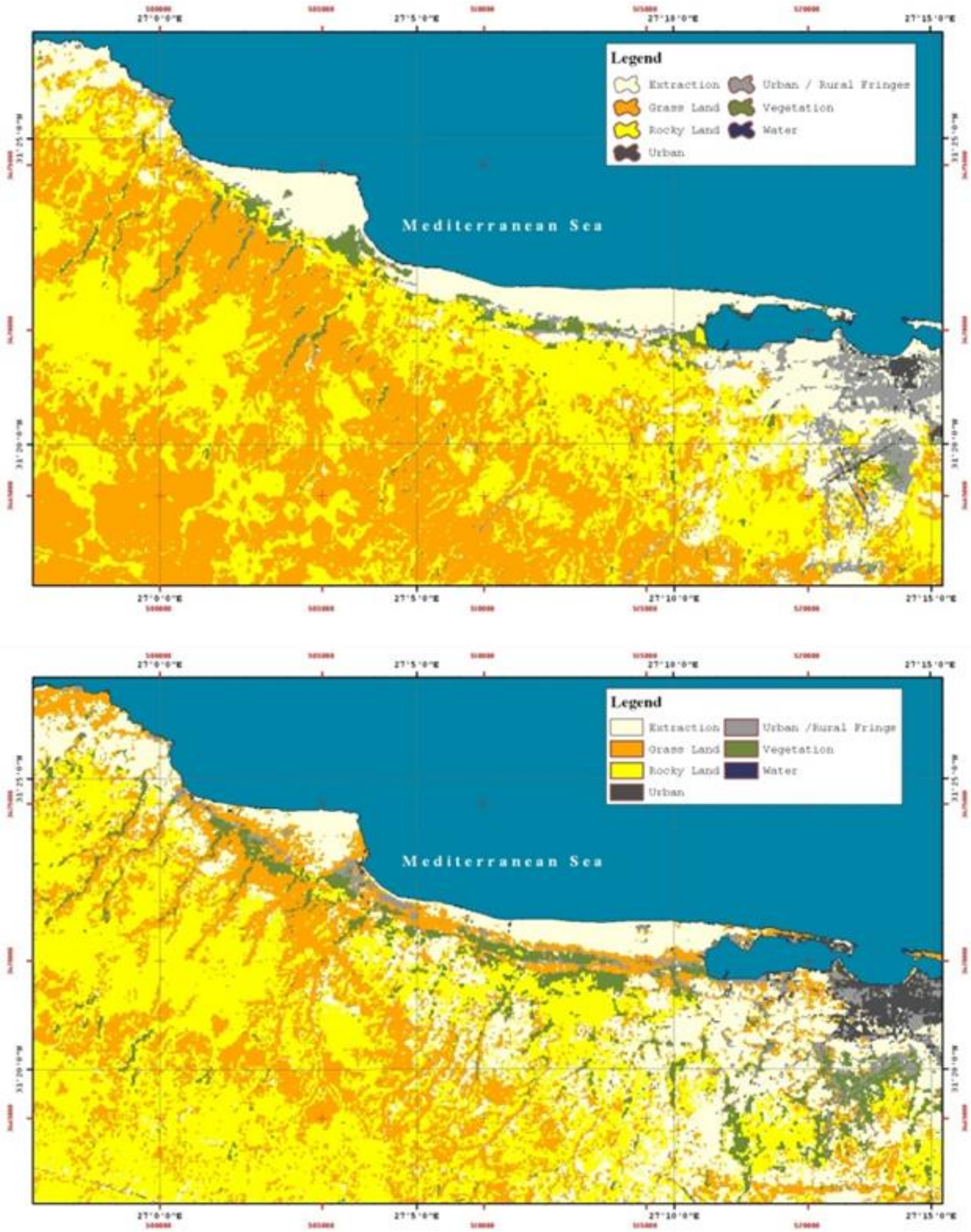

Figure 4 : Land Cover Classification: (a) 1987, (b) 2002.

			Classified Map							
			Water	Urban	Urban / Rural	Vegetation	Grass Land	Rocky Land	Extraction	Total
Reference Data	1987	Water	3	0	0	0	0	0	0	3
		Urban	0	14	1	0	0	0	0	15
		Urban / Rural	0	0	13	0	0	0	0	13
		Vegetation	0	0	0	10	0	1	0	11
		Grass Land	0	0	0	0	10	0	0	10
		Rocky Land	0	0	0	0	0	10	0	10
		Extraction	0	0	0	0	0	1	12	13
		Total	3	14	14	10	10	12	12	75
	2002	Water	5	0	0	0	0	0	0	5
		Urban	0	16	1	0	0	0	0	17
		Urban / Rural	0	0	14	0	0	0	0	14
		Vegetation	0	0	0	14	1	0	0	15
		Grass Land	0	0	0	0	17	0	0	17
		Rocky Land	0	0	0	0	1	15	0	16
		Extraction	0	0	0	0	0	0	12	12
		Total	5	16	15	14	19	15	12	96

Table 2: Error Matrix of 1987 and 2002 Classification Data.

- Transition probability matrix: transition probabilities express the likelihood that a pixel of a given class will change to any other class (or stay the same) in the next time period.
- Transition areas matrix: that expresses the total area (in cells) expected to change in the next time period.
- Set of conditional probability maps: a map for each land use class which presents the probability that each pixel will belong to the designated class in the next time period.

On the other hand, cellular automata approach considers the dynamics of change events in proximity; this means that the areas will have a higher tendency to change to a specific class when they are near existing areas of the same class. A cellular automaton is a cellular entity that independently varies its state based on its previous state and that of its immediate neighbors according to a specific rule (Malamud, 2000). Markov chain analysis in this context may provide a tool to model the historical pattern of land use dynamics. Merging cellular automata with Markov chain analysis expands the capabilities of modeling process to include non-historical impacts. These impacts are expressed as anthropogenic factors that present society demands and experience.

To produce land use maps, simple recoding process is done to convert the land cover classes to land use. The final land use maps are presented in figure 5a,b. The dynamics of land use changes between 1987 and 2002 are analyzed by the processing of the previously prepared two land use maps in a Markov chain analyzer, which produced a transition probability matrix and a conditional maps set.

The transitional probability matrix is presented in table 4. In this table, each cell describes the probability of transition from 1987 land use classes presented in rows to 2002 land use classes presented in columns. The set of transitional probability maps is depicted in figure 6. In order to produce a projected land use (for year 2006), the transitional maps and the probability transitional matrix are used in a Markovian chain analysis using 2002 land use map as a base for the analysis (figure 7).

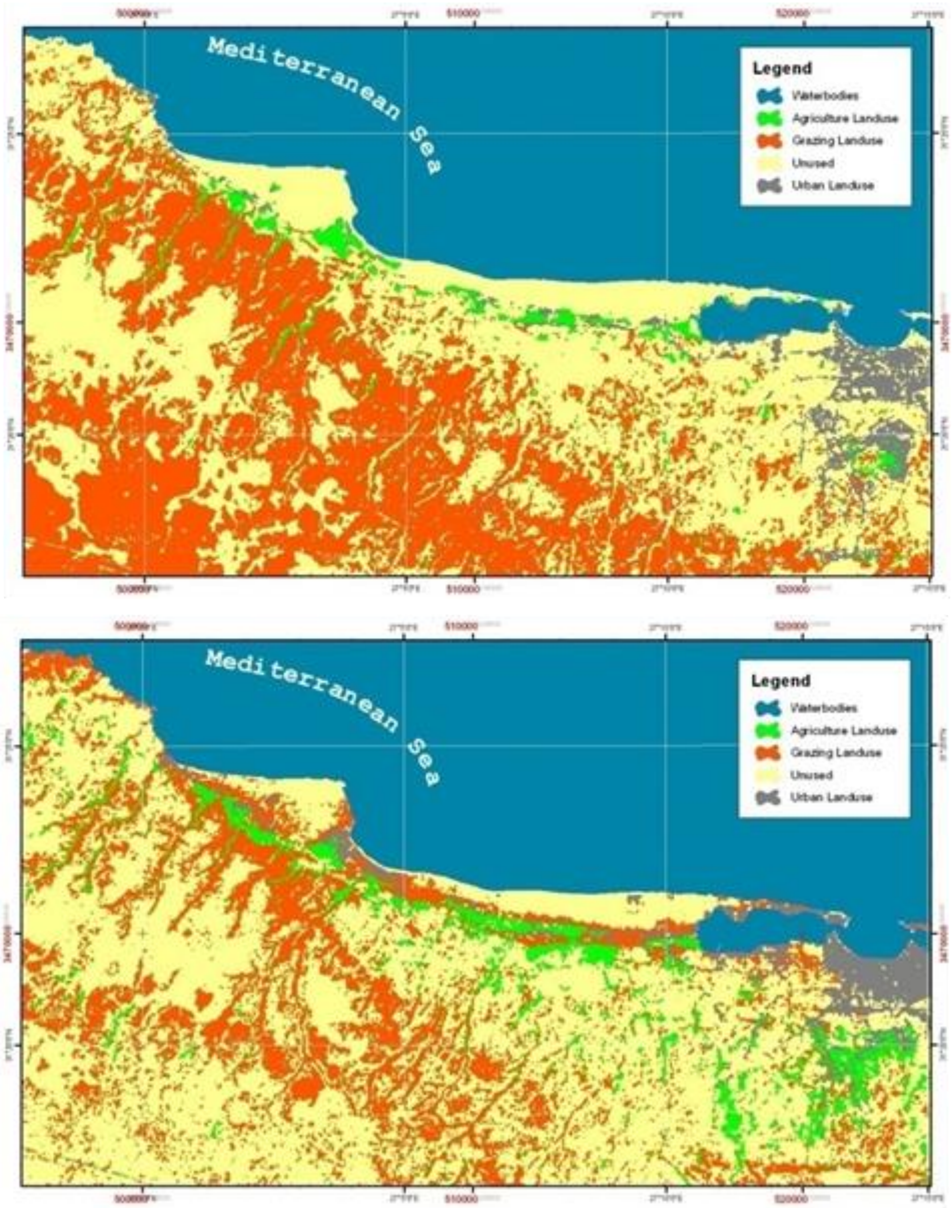

Figure 5 : Land Use Classification: (a) and (b).

		2002 Land Use Classes			
		Urban	**Grazing**	**Agriculture**	**Unused**
1987 Land Use Classes	**Urban**	0.8066	0.0811	0.0794	0.0329
	Grazing	0	0.4898	0	0.5102
	Agriculture	0.0889	0.1519	0.7592	0
	Unused	0.0097	0.1497	0.0514	0.7892

Table 4: Transition Probability Matrix.

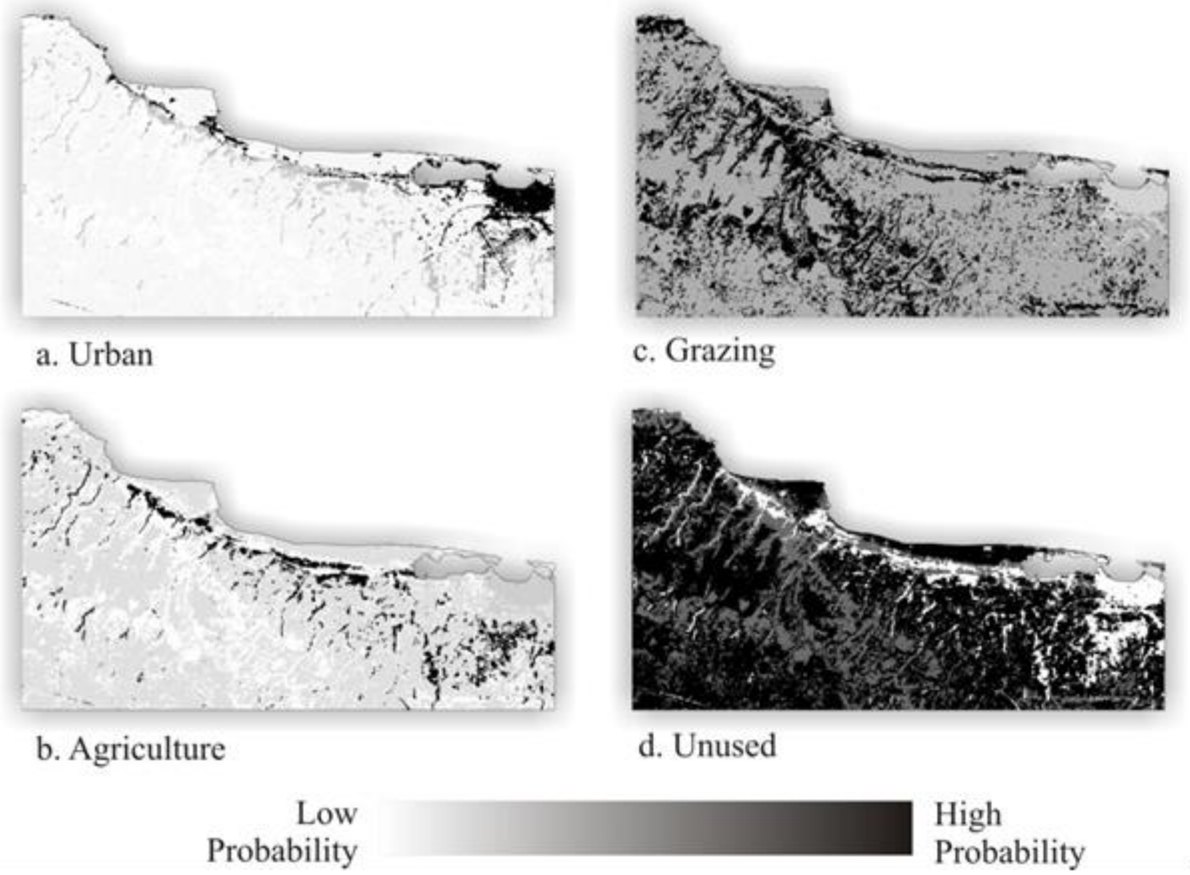

Figure 6 : Transitional Maps for (a) Urban, (b) Agriculture, (c) Grazing, and (d) Unused areas.

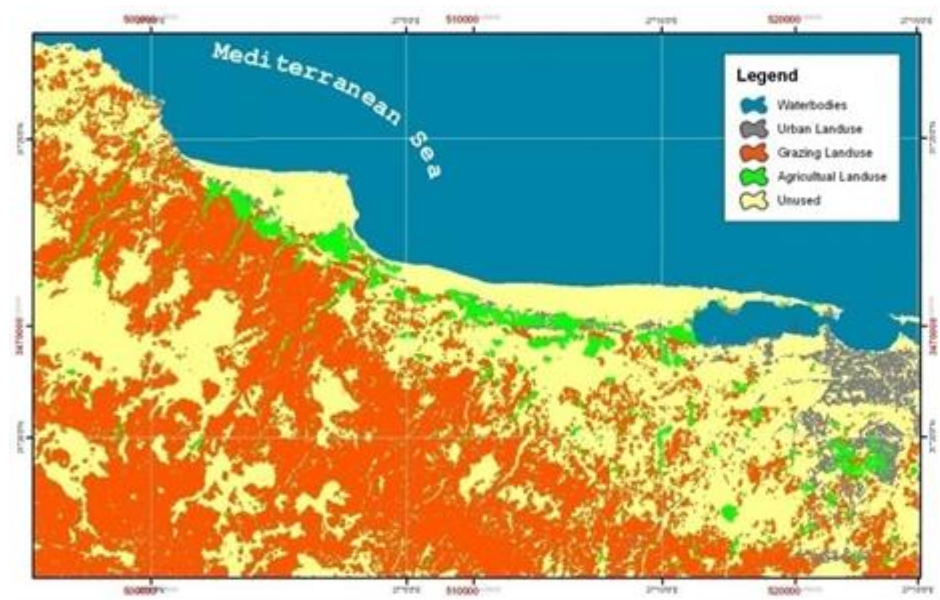

Figure 7 : 2006 Land Use Projection Map.

Enhancing Modeling Results

In order to enhance the projection results, selected socioeconomic data are included in the analysis within a GIS platform. A simple questionnaire is designed to help a participation group to express their preferences about the land use development. A small sample group of 14 members is selected (local community, investors and decision makers). The main purpose of the questionnaire is to identify the factors that influence land use development trends and directions. The results from this step could be enhanced in the future by increasing the sample size and including other stakeholders as well as experts and professionals.

Based on experts' opinion and discussions, a list of 25 factors is developed (table 4). These factors are considered the most influential on the current land use change rates and directions. In addition, the participants were asked to weight the factors in terms of their relative importance to different land uses. Based on this analysis, three suitability maps were developed according to the following equation:

Eq.1

Where S is the suitability of the considered land use activity, w_i is the weight platform. expressing the importance of the criterion x_i. The significance of each factor is presented using positive sign for major driving force and negative sign for hindrances. By mapping and combining criteria, the suitability maps are developed (figure 8). This information was used to enhance landuse forecasting by identifying isolated pixels and reassigning these pixels to a proper land use class (figure 9).

Code	Factors	Urban	Agri.	Graz.
A	Location within City Limits	□	□	□
B	Land Aspect	□	□	□
C	Land Slope	□	□	□
D	Proximity to Social Facilities	□	□	□
E	Proximity to Agricultural Land	□	□	□
F	Proximity to Coastal Line	□	□	□
G	Proximity to Educational Facilities	□	□	□
H	Proximity to Fractures	□	□	□
I	Proximity to Faults	□	□	□
J	Proximity to Grazing Land	□	□	□
K	Proximity to Urban Settlements	□	□	□
L	Proximity to Matrouh's Airport	□	□	□
M	Proximity to Matrouh City	□	□	□
N	Proximity to Medical Care Facilities	□	□	□
O	Proximity to Main Roads	□	□	□
P	Proximity to Power Facilities	□	□	□
Q	Proximity to Power Lines	□	□	□
R	Proximity to Railways	□	□	□
S	Proximity to Security Facilities	□	□	□
T	Proximity to Wadies	□	□	□
U	Proximity to Water Facilities	□	□	□
V	Proximity to Waterline	□	□	□
W	Proximity to Water Wells	□	□	□
X	Soil Type	□	□	□

Major driving force ○ Neutral ⦿ Hindrance ●

Table 4: List of Factors Affecting Land Use Dynamics in the Study Area.

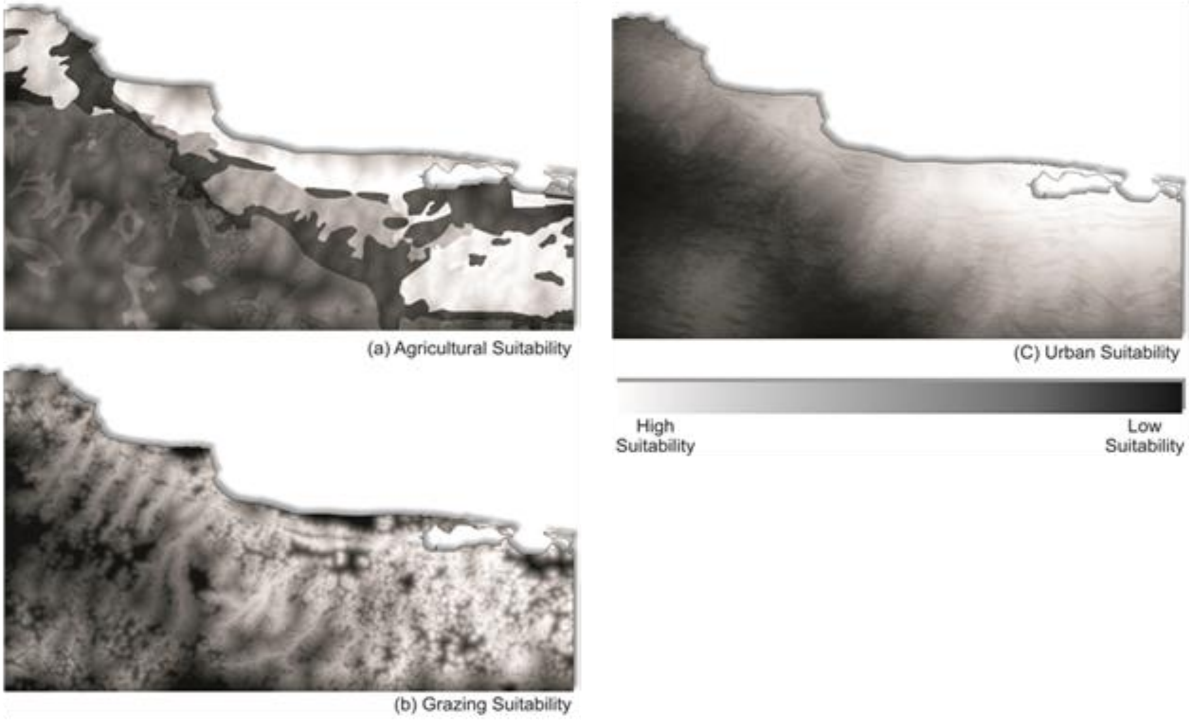

Figure 8 : Suitability maps for (a) Agriculture, (b) Grazing and (c) Urban.

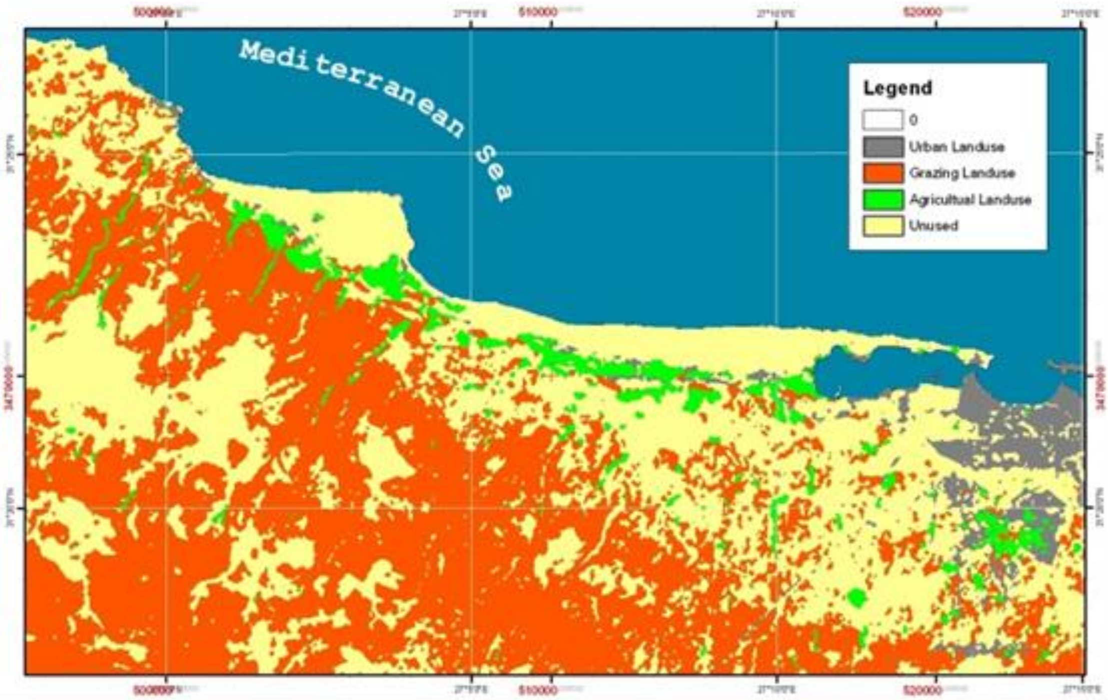

Figure 9 : Enhanced Forecast Land Use Map for 2006.

Evaluation of Forecasted Results

To evaluate the results of the modeling process, two procedures are used: the qualitative and the quantitative approaches. The qualitative approach is based on the visual comparison of the projected land use with the existing land use in 2006 as depicted from an IKONOS very high resolution imagery. The visual comparison revealed good similarity between the predicted results and the actual condition at 2006. The quantitative approach expresses the accuracy of the model results in a more objective form. A simple error matrix is used to calculate the model accuracy. 445 points are distributed randomly over the study area, and then the land use in both reference image and projected map are recorded in a pivot table (table 5). In this table, the projected map classes are presented in columns and the reference data classes are presented in rows. The cells contain the number of points that were classified for the same land use class in both model data and reference data. These cells present the correct forecasting, while the other cells present the erroneous forecasting. The overall accuracy assessment demonstrates an accuracy of 69.5%, which is considered acceptable in landuse models using Landsat imageries.

		Model Results				
		Urban	**Agri.**	**Grazing**	**Unused**	**Total**
Reference Data	**Urban**	50	5	7	12	74
	Agriculture	11	55	16	14	96
	Grazing	10	11	86	15	122
	Unused	11	13	11	118	153
	Total	82	84	120	159	445

Table 5: Error Matrix for Model Results.

DISCUSSION

The aim of this study is to establish a technique for modeling land use changes and urban growth using both historical spatial information and anthropogenic data. The main emphasis of the adopted process is to formulate a model for land use dynamics using a quantitative Markovian chain analysis. A primary projection for future land use map is created using an inverse Markovian chain cellular automata. The accuracy of this map is enhanced by incorporating anthropogenic factors to assist in the spatial allocation of each land use type. The accuracy of the model is affected by three main factors:

- The resolution of imageries used to develop land cover / land use maps. In this study, Landsat imageries provided a moderate resolution suitable for regional and sub-regional level of spatial modeling.
- The accuracy of classification process, as it is the main source of error propagation in the model. Highly accurate classification process is strongly recommended to maximize the accuracy of the model.
- For a reliable and an efficient Participatory GIS (PGIS), it is recommended that more diverse stakeholder participation is adopted, in order to ensure good representation of the anthropogenic factors and better accuracy in the projection of growth directions.

Regarding landuse dynamics, the projected land use map for 2006 estimates an urban growth of Marsa Matrouh city towards west and south, especially along current roads and smaller urban agglomerations. It also predicts some agriculture development around current agriculture land and Bedouin settlements. These results illustrate the natural growth trends in the area and present an important indicator for future development. Those trends should be seriously considered while preparing strategic urban plans and formulating future urban policies and management frameworks.

CONCLUSION

The geospatial modeling framework presented in this paper is site independent and proved to have adequate accuracy for a wider implementation in other spatial locations in Egypt. In general, historical data acquired from satellite imageries of medium to high resolution could be easily provided in public institutions in Egypt (the General Organization for Physical Planning, Ministry of Economic Development, the National Authority for Remote Sensing and Space, etc..). It is therefore recommended to adopt this process in the land use planning activities in order to forecast dynamics of urban growth at both local and regional levels.

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