

Application of Remote Sensing and GIS to Assess the Construction Pressure on the Environment of Algiers (Algeria) During the Three Last Decades and Their Evolution by the Use of Markov Chain

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Abstract

Like many cities in North Africa, limited in the south by steppe areas and indeed for some others by desert, its demography shows a steep rise, making a deep imbalance between the highly populated north and the south with a low population. This demographic pressure increased considerably during the period from 1990-2000, because of the extremely unstable political situation. This influx was accompanied by the development of new infrastructures (road and railway networks) and the densification of the economic fabric from 2005 onwards which led to the Algiers department being divided into three zones moving from North to South and in bands from East to West. These pressures were translated by a quick urban sprawl primarily along the Mediterranean ridge and secondarily inside the plain of Mitidja, precisely in the eastern part of the department in the context of an almost total absence of an official town development plan. Built up areas have increased spurred on by economic planning without preserving the balance between categories of land-use which has led to the disappearance of numerous wet zones, the reduction in underlying groundwater resources and the pollution of surface water in the main rivers crossing the plain. Cartographic analysis and the prediction of land-use at 2020 confirms the persistence of the process indeed its aggravation particularly near main roads and progressively inland creating new urban centres, even occupying flood plains (Oued El Harrach).

Keywords: Algiers; Environment; GIS; Land-use; Markov modeling; Remote sensing

Introduction

Algiers, the main Algerian agglomeration, has seen its geometry develop rapidly over the past thirty years under the impetus of two principal factors: administration and industrialisation centered on Algiers and since 1990, a conflictual political situation. To these two factors can be added a lack of development planning which would have guaranteed the intelligent organization of urban spaces and the protection of the environment. The introduction of a coherent development policy for the city which could lessen the effects of this phenomenon over the medium to long term hinges on an assessment of the current dynamic and the prediction of future development in the Algiers area.

Predictive modelling of land-use change can be used as an unequivocal means to materialize the trajectory that a given area can take under the impulsion of factors, usually of anthropogenic origin. It also serves as a tool for organization and space management with a view to maintaining an often precarious balance, which can ultimately, in the case of non-preservation, result in disruption of territorial dynamics (economic and social). The evolution of occupation is a complex process induced by a combination of many factors (physical, biological, hydrological, human, etc.) often subject to uncertainties [1].

The consequences of these changes are often dramatic to ecosystems and more broadly to humans. The Algerian agglomeration has lost close to seventy per cent of its wet zones (Oued Smar: 500 ha), seen a reduction in underlying groundwater resources (Mitidja resource: piezometric level down by 100 m) and persistent pollution of its main rivers due essentially to industrial activity (Oued Smar and Réghaia industrial zones). Thus, the groundwater level in the plain of Mitidja has dropped by about 70 meters in 20 years. Disruption of hydrological processes as assessed by an increase in evaporation, evapotranspiration and in interception [2] lead finally to more acute water shortages.

These changes also affect the ecosystem as a biotic component with the decline of biodiversity [3,4]. Recent technological innovation in remote sensing, GIS and space modelling has produced a wide range of tools of use when seeking to develop reliable land-use maps and monitor its change over time, taking into account its temporal dimension and finally predicting future analysis. All of these techniques and their combined use allow us to provide concrete and measurable responses to land-use changes and to identify the factors (variables) involved in these processes.

Two objectives are covered by the paper:

- Evaluate the degree of land-use change under the influence of the first political tensions in the 90s, new infrastructure (transport, roads etc.). This step is based on the comparative analysis of

different satellite images (1987, 2001, 2005 and 2013). We also identify the natural factors favoring these spatial changes.

- Evaluate the trajectory of the department of Algiers in terms of land occupation for the next 25 years, which could show a further strengthening of the extension of construction at the expense of agriculture and entry into an unprecedented land crisis.

Materials

Study area

The department of Algiers is one of the most populous departments of Algeria. It covers an area of approximately 1190 km² of elongated shape along an east-west axis (Figure 1).

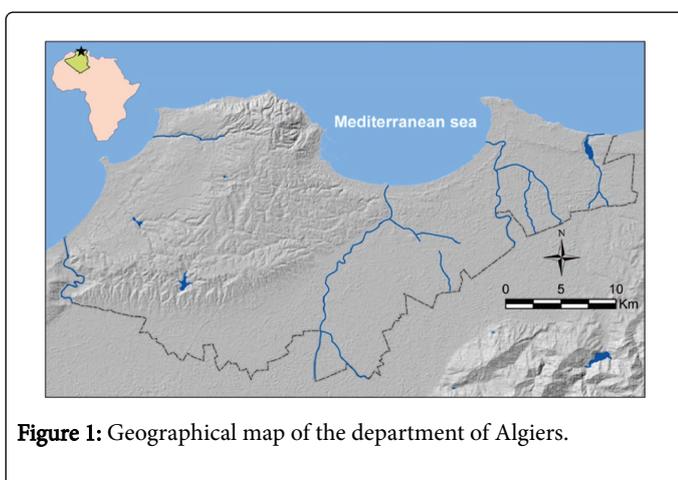


Figure 1: Geographical map of the department of Algiers.

The region is bounded on the north by the Mediterranean Sea, bordered on the south by the chain of Atlas Blida and administratively by the Department of Blida, to the east by the department of Tipaza and to the west by the Boumerdes. The average altitude of the department rarely exceeds 100 m with a high point on the heights of Algiers of about 250 m above sea level. On the morphological map, a north-south divide marks the Algiers relief with the hills around Algiers, mainly of metamorphic origin (tuff) relayed to the south by the Mitidja plain which consists mainly of Quaternary age alluvium resting on Plaisancian marl. Soil fertility and abundance of underground water give this part of the county its agricultural specificity which is primarily focused on citrus production and vegetable crops and low on cereals.

For the hydrological field, the department and its floodplain are drained by 3-4 major rivers (Oued El Harrach, Oued Hamiz, Oued Djer, Oued Mazafran), all of which flow into the Mediterranean Sea.

Data

The combination of several data elements coming from different sources has enabled a precise cartography of the expansion of Algiers to be drawn up. Satellite images constitute a cheap and effective method of constructing land use maps and of following the changes in land use in space and over time. The availability of images captured at different dates and with suitable picture quality together with inventories carried out directly on site in 2011 gives us unequalled tools for the construction of maps and following land use change over time. Raw data have been combined with inventories produced during

on-site visits in order to establish a precise classification of land use throughout the Algiers agglomeration.

Four pairs of images covering the entire watershed area of the Algiers were used: Landsat4 TM (21/06/1987) Landsat 7 ETM (21/07/2001), Landsat 7 ETM + (14/06/2005) and Landsat 8 OLI_TIRS (12/06/2013) (Table 1). Resampling was carried out on maps created from previous images in order to homogenise them across the whole of the territory covered by the agglomeration. To this first group of data from satellite images was added data from other sources in order to produce the development model showing changes in land use (i) MNT using a resolution of 30 m per cell, slope, aspect, (ii) shapefile (shp) vector layers of roads, of the hydrographical network. This group of maps was projected in the Universal Transverse Mercator for North Africa Datum coordinates system zone.

Data Set	Source	Date
Landsat Imagery	US Geological Survey (USGS)	1987, 2001, 2005, 2013
Digital Elevation Model	ASTER (METI/NASA)	

Table 1: Data sources and types.

Other maps processed using Idrisi were also integrated into the modelling phase. Thus maps showing distances to roads, to the hydrographical network, to buildings, to forests, slopes and aspect have been produced. The use of slope allows a classification of areas and to extract those with the least steep slopes which are the most favorable to urban expansion.

Methodology

The focus on this dimension has formed the basis for the development of model-based algorithms, leading finally to several types such as mathematical modelling, statistics, evolution (multi-agent systems), cellular automata [1,5] and an approach called "approximative" uncertainties [1,6-9]. Other models based on Markov chains or expert models have been widely used. With many land-use prediction models such as LCM (Land Change Modeler), Markov chain, CA-Markov and GEOMOD, considered effective for predicting the evolution of the land-use due to their combining GIS with their potential processing, ecological simulations have been developed [10-12].

This section focus on the description of the main components used for the urban growth models of Algiers to evaluate. A methodology overview presented in Figure 2 show the main components carried out (1) land use classification of initial multi-temporal satellite imagery, (2) creation of predictive maps for 2005 and 2013 to calibrate the model and finally (3) integration of Markov (MLP) chain algorithm to prospect urban processes for 2020 and 2030.

Land use production

The cartography of land use was carried out 1987, 2001, 2005, and 2013) on the basis of satellite images available and extracted from the USGS site (path, row). A resolution of thirty m was adapted to all the images which were classified into the following categories: (1) conifers, (2) mixed forest, (3) meadow, (4) water, (5) buildings. The absence of a reference framework in Algeria meant that we could not establish a normalised classification. The groups as they are constituted are the

result of analyses carried out in situ from April 2006 to December 2011, together with a European reference framework (IFEN France) (Figure 3).

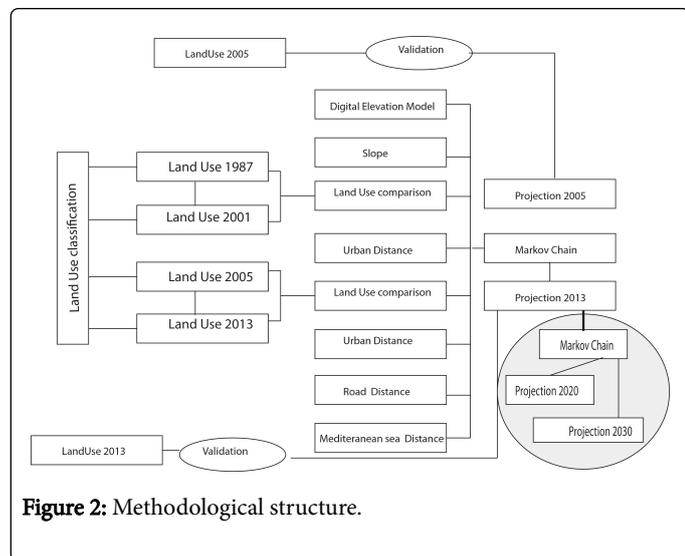


Figure 2: Methodological structure.

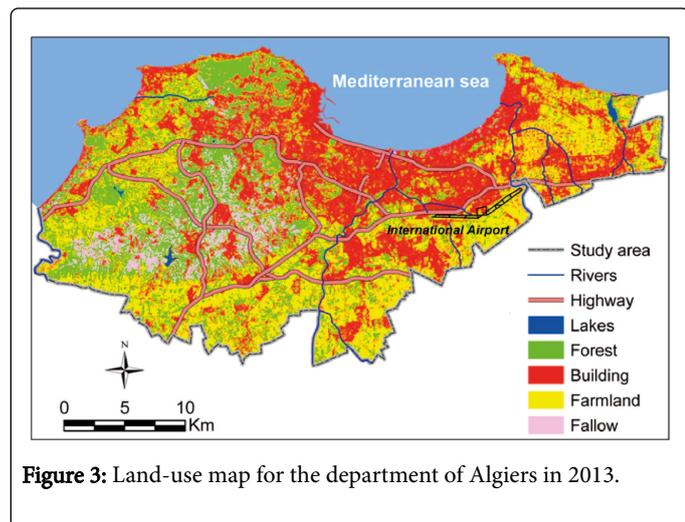


Figure 3: Land-use map for the department of Algiers in 2013.

A classification based on the algorithm of maximum likelihood) was applied on the basis of a sampling from the on-site analyses which gave rise to a map of land use for each satellite image. The application of this methodology was subject to a series of rules viz. (i) identification of the best learning sites for each land use type after an iterative selection process. (ii) Classification of multispectral images at pixel level of all the groups simultaneously. (iii) and finally, the creation of land use maps and their verification directly on site in order to measure the exactitude and so the conformity of the results of processing for satellite images This comparative analysis was carried out to the east of Algiers, along the sea front, to the south of the largest airport, on the heights of Algiers where the last forest sectors remain, and finally towards Boulsmail (west). The degree of precision varies but is around 90%.

All these images correspond to the same season (dry season) in order to avoid possible classification errors due to seasonal variations in vegetation. They also have the same spatial resolution (30 m). However due to the heterogeneity of the acquisition dates of the

images, spectral resolution; of angle and finally of the rotation of images, pre-processing prior to classification was carried out to reduce the potential differences between the images [13-15].

An evaluation of the sampling quality was carried out on the basis of separable index calculation between the spectrums [16,17]. Two indices were used, namely the Divergence Transform (DT), the Jeffries - Matusita (J-M) [18]. These indices vary along the interval of 0-2. Higher values of these indices indicate better separability. Addition of physical geographical data such as linear distance to road, to river, to Mediterranean Sea, slope, aspect is pertinent to model urban growth [19]. The Idrisi software was used to build in this information.

Land change modeler: land-use change prediction

The maps of land use made using processing by remote sensing of satellite images were imported into a SIG Raster (Idrisi: Taiga, Selva published by Clark Labs) to be rastered and transformed into a grid of the same resolution. This matrix representation (line, column) of spatial information gives the possibility of adding quantitative data concerning land use at each cell level. This format, in accordance with the expectations of Markov Transition Chains makes it possible to evaluate the state of each cell among n given states.

In this study, we used a stochastic approach based on the method of Markov. For the implementation of Markov chains, several assumptions were made including consideration of land-use change as a stochastic process, and the different categories are the states of a Markov chain [20-23]. A process is called stochastic if its (X_t) process at an instant t depends on the value (X_{t-1}) at instant t-1, and does not depend on the sequence of values $X_{t-2}, X_{t-3}, \dots, X_0$ (process values before instant (t-1)). This string can be expressed as follows:

$$(1) P\{X_t=a_j|X_0=a_0, X_1=a_1, \dots, X_{t-1}=a_i\}=P\{X_t=a_j|X_{t-1}=a_i\}$$

Where:

X_0, X_1, \dots, X_{t-1} are the observed values of the Markov chain in the discrete-time (0,1, 2 ...t-1).

The matrix $P \{X_t=X_{t-1}|a_j=a_i\}$ is known as the transition probability and indicates the probability that the process will make a transition from state i to state j over a period of time t.

For assessing the evolution of land-use in the department of Algiers and the practical application of this method, we used the prediction module (LCM: Land Change Modeler) implemented in GIS Idrisi (Taiga, Selva) [10].

This module allows the identification of the gradual transition from one category to the other as a sequential process, which provides both graphic and cartographic representations. This also increases the capacity to evaluate land-use changes. The assessment is based on the integration of static variables and/or dynamic, called explanatory, variables. The individualization of the factors responsible for these changes and the extraction of explanatory variables are used in the generation of predictive maps for 2013 by applying different methods. A qualitative analysis of the explanatory variables, their transition and the modelling quality, more precisely the obtained results will be carried out in the context of developing predictive maps for the future 25 years.

For predicting the evolution of land-use in the medium term, the integration of so-called planning reinforces variables and/or potential changes in constraint variables and gives relatively accurate results depending on the degree of impact of the above elements. The tool also

provides functions related to territorial planning, and decision-making.

Change assessment and identification of explanatory variables

The processing of results using 4 satellite images led to the production of maps and individualized the global dynamics of land-use throughout the entire Algerian territory. The results of the LCM module for the prediction maps of 2005 and 2013 calculated respectively from the pairs of (1987, 2001) and (2005, 2013), which were subjected to double comparison with the reference maps from satellite images for the same dates. This analysis led to the identification of first the main regions of change and then their potential interaction with physical, hydrological, climatic and anthropogenic factors. These factors are therefore considered as explanatory variables to be included in the LCM model for the prediction of land-use change over the next 20 or 30 years. These were selected on the basis of their explanatory potential, evaluated using Cramer's V coefficient. It compares each variable with different categories from the maps in 2005 and 2013 to consider only those whose coefficient is greater than 0.40 [10]. The persistence, loss, gain and the potential substitutions of different categories were estimated in the form of pivot tables for each map according to the method proposed by Pontius et al. [24].

In total, 10 variables were identified and selected for predictive modelling of land-use of the department of Algiers: DEM, slope, aspect, distance to roads, distance to the hydrographical network, distance to constructions in 1987, distance to forest in 1987, distance to farmland in 1987, distance to bare soil and grassland in 1987, and distance to the sea in 1987.

The strong concentration recorded over the past 20 years on the coastal fringe along an East-West axis suggests the attractiveness of the sea. These habitats aggregation coupled with the availability of land in the flat areas of the plain has produced the urban centers on the southern fringes of the historic center of the capital and the distance from other buildings became a key factor in the overall organization of the Algiers area.

Modeling the land-use changes

To calculate the probability of occurrence for each transition, we used the LCM model: The logistic regression that takes into account the changes and potential explanatory variables [25] and the Neural Network of Multilayer Perceptions (MLP) [26,27] which assesses the nature of the relationship between the changes and the explanatory variables.

Modelling the evolution of land-use in the department of Algiers was performed by applying the "Markov chains" method, using respectively the reference maps of 1987 and 2001 and the transition probability initially calculated. The first results the areas of loss and gain for each category for the years 1992 and 2001 to be identified. To calibrate the model, we conducted a comparative analysis with reference images from the processing of satellite images for the same dates. Two methods were used for model validation: the visual and the statistical approach. The combination of both is important as differences shown by the first can highlight dissimilarities and the second can, by calculating, confirm or refute these results. The use of the "validative" module provides a means of assessing the degree of concordance between the maps for the same categories and estimates

of ROC (Relative Operating Characteristic). The closer this value is to 1, the larger the concordance is, and the result is therefore better [11].

Results and Discussion

Urbanisation in the Algiers department area

The first analysis used both visually and by comparison of satellite images from 1987 and 2001 gives acceptable results which account for nearly 90% of the land-use. Overall, the water categories remain stable and therefore unchanged despite land occupancy strongly related to the hydrographical network. Conversely, the sharp contrast between construction and agriculture confirms the increase of the former at the expense of the latter, which shows significant reductions in its surface. Moreover, for these two years, buildings occupy the most space in terms of surface area, thus confirming the significant increase in construction during this decade. In parallel with the first phenomenon, grasslands and forest areas, generally located on the heights of Algiers, decline gradually due to the shortage of land recorded in recent years.

Extending the analysis to all satellite missions (Landsat4 TM (21/06/1987), Landsat7 ETM (21/07/2001), Landsat7 ETM+ (14/06/2005) and Landsat8 OLI_TIRS (12/06/2013)) confirms the general tendency and the replacement of agricultural spaces with built environment, at first in the plains areas and then from late 2000 in the highlands of Algiers. This same phenomenon is also observable in the southern areas of the county near the foothills of the Bildean Atlas.

The built surfaces show a significant increase at a relatively high rate which alone represents almost 50% of land consumption. This increase comes at the expense of farmland particularly in the plains areas. The rate of farmland loss is almost equivalent to the recorded gains in built surface areas. They are followed by a relatively modest gain in farmland and forests. Indeed, the recent financial support applied by the Algerian state in the past 15 years to promote agriculture, in particular vegetable production, explains the recent renewal of interest in and the valorization of a large proportion of what was initially wasteland (Figure 4).

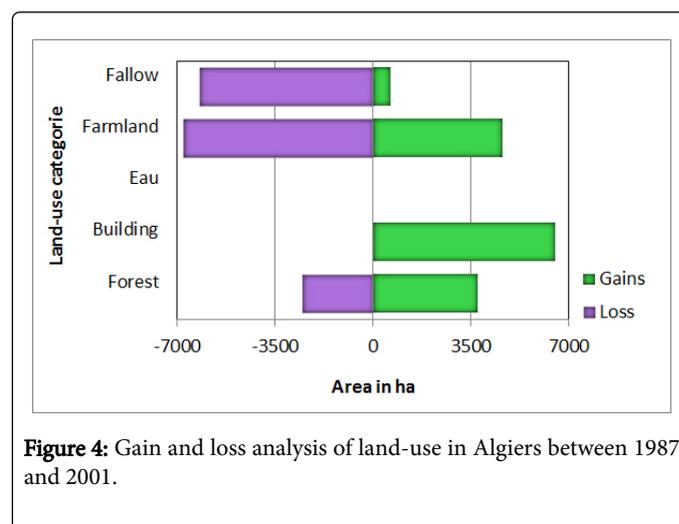


Figure 4: Gain and loss analysis of land-use in Algiers between 1987 and 2001.

However, the loss in farmland remains much higher than the gain. The grasslands and shrub surfaces also recorded significant losses especially on the highlands east of Algiers. However, the gain is very small and insignificant.

Spatio-temporal change in the Algiers department area

At this moment in time, the territory in Algiers and its surrounding area has attained such a state that it is almost impossible to find none built up surfaces anywhere in the central core. This situation is extending outwards, reaching the edge of the urban area, giving rise to secondary urban poles which are in a continual state of growth.

This fact is reflected in the rapid change of land-use from arable into construction as shown in Figure 5. Urban expansion of the city of Algiers occurs in two stages. First, along an east-west axis by the seafront especially in western areas of the city of Algiers marked by topographical constraints (the heights of Algiers and slope > 10°) then east from the early 90s to the foothills of Ain Taya.

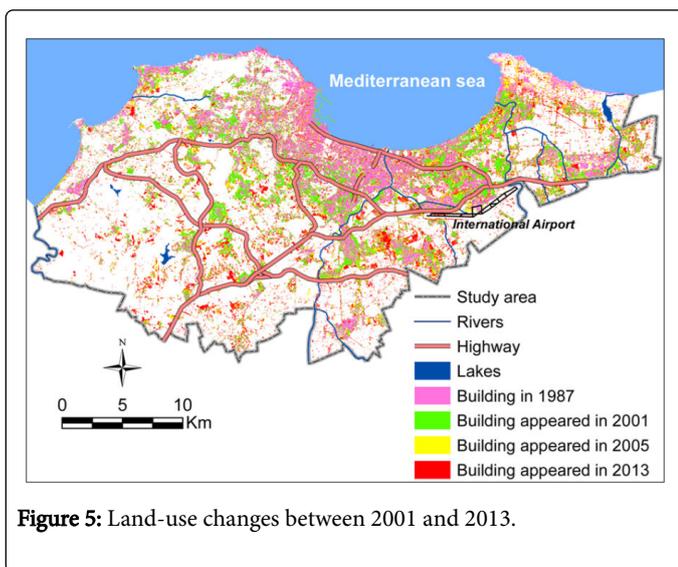


Figure 5: Land-use changes between 2001 and 2013.

This momentum has accelerated since 2000 by penetrating the depths of the Mitidja to the highlands of the cities of El Harrach and Bordj El Kiffan, giving birth to a second North-South urban axis. This second stage of urbanization is much faster and has consumed far more agricultural areas marked by very low slopes.

New road networks between 1980 and 2000 had very little influence on the urban dynamics of Algiers, they form a quasi-barrier at the "southern bypass" axis, thus splitting the department into two blocks: the town of north Algiers (urban) and agricultural areas to the south dotted with small urban centres that have grown up since the mid-2000s.

Using the Markov Chains method makes it possible to calculate the probabilities of changes in land use in the department of Algiers in order to individualise preferred extension zones, sectors under pressure, town planning in terms of services required for newly urbanised zones, the extension or not of green spaces for recreation and leisure. Inversely, the decline in agricultural spaces has drastically reduced this activity, leading it to all but disappear. All the results of analyses carried out on maps from images going from 1987 to 2010 confirm this assessment and show a likelihood of the remaining agricultural zones at the edge of the department coming under permanent if not increased pressure.

Model calibration, validation and scenario generation for 2020 and 2030

The cartographic results of predictive modeling allow us to evaluate the degree of expansion of the urban fabric of Algiers and especially the decrease in agricultural land use in favour of construction, a process accelerated by several phenomena: (i) the period from 1990 to 2000, called the "black decade", marked by political interference and thus a mass exodus from inland to the major urban centres in the north and (ii) new infrastructure, especially roads and railways, (iii) the absence of a clear legislative framework regulating urban planning throughout the territory.

In order to validate the model, the construction of the confusion matrix for the analysis of correspondences between the reference maps (1987 and 2001) and those obtained using the two methods, namely MLP and Logistic Regression are necessary. Potential errors based on each model, omission and commission errors are evaluated. It corresponds to the relationship between the number of correctly assigned pixels and the total number of pixels in the image [27]. The adjustment between the reference maps and the maps generated by modelling is evaluated using the Kappa index [28]. Model validation therefore allows the building of predictive maps for the years 2020 and 2030 (near future) based on the previously selected explanatory variables for each transition.

Evaluation of explanatory variables: The identification of necessary explanatory variables for the model based on the calculation of Cramer's V index and its associated probabilities are calculated and used in the evaluation process of the relationship between the explanatory variables and land-use categories. In total, ten variables were used giving values of the Cramer V coefficients varying between 0 and 0.8. Four factors are strongly involved in this dynamic replacement of agricultural areas and grasslands by built up areas since the early 1970s. They are the distance to roads, slope, distance to agricultural land and meadows and finally the distance to the sea. This last factor undoubtedly played a role between 1970 and 1990, but its influence has tended to decrease due to waterlogging recorded since 2000.

All other factors are involved to a lesser degree in the global dynamics of substitution.

Then come the areas of grassland and shrub that are closely conditioned by the topographical criteria (slope and aspect), with Cramer V coefficients > 0.8 and more weakly by the presence of land of the same type (0.37). The distance to water and more particularly to the hydrographical network plays a very small role.

Overall, the strongest associations link construction to the road network, which confirms that the recent development of transport infrastructure carried out under the development program in 2010-2014 has had a profound upon the Algiers urban landscape and increased the pressure on land particularly in plains areas. The degree of the relationship between the different analyzed variables, thus allows their inclusion in the sub-model for the prediction of land-use in the short and medium term for the department of Algiers.

Transition sub-model: running and calibration: Only variables with high Cramer V coefficients are included in the calculations. However, we have integrated all variables to benefit from the contribution of each of them to the evolution process.

Overall, the correlation degree (ROC) is relatively high, indicating a rate of explanation of land-use changes by fairly significant different explanatory variables. Their values are greater than 0.80, which

confirms the importance of these variables in explaining land-use changes. What is shown by the regression coefficient corresponds to the direction of the relationship between the explanatory variables and the transition (direct or reverse). However, two variables show slightly lower values indicating the slightly lower rate of passage of forest and grassland areas into building due to the search for flat land and therefore in plains areas.

Two variables displayed their net involvement in the processes of transformation of land, they are topography (slope and aspect) and the distance to the road network.

Iterative calculations to calibrate the model gave the results shown in Table 2. The root mean square error of the training is of the order of 0.48, the same as the test before calibration, and reached 0.14 afterwards. The accuracy rate after calibration increased to 76.63% and stability is reached after 7500 iterations.

Stopping criteria		Running statistics	
Parameter	Value demanded	Parameter	Value obtained
RMS	<0.01	Learning rate	0.0002
Training RMS	<0.50	Training RMS	0.2536
Testing RMS	<0.50	Testing RMS	0.2542
Accuracy rate	>75%	Exactness rate	77.34%

Table 2: Results obtained from the calibration of the transition sub-model.

Land-use prediction in the department of Algiers: The calculation of transition probabilities for different periods confirms the results of visual analysis and especially the verifications made on the ground. Overall, the strongest transitions, observed in the early 90s, continue through 2013 as a common urban extension at the expense of agricultural land. This extension is also at the expense of fallow areas, trees and finally forest especially on the highlands of Algiers. The slope and moreover the topographical constraints are only a partial obstacle.

Water remains relatively stable in terms of surface area and no significant changes are noticeable. It is important to note that these same elements have seen their associated land shrink, in particular the floodplains of large rivers and areas of extreme flooding.

To estimate the general tendencies in the medium and long term, a series of predictive calculations were performed for both the model calibration and to create predictive maps for the years 2020 and 2030. Two predictive maps were created respectively for the years 2005 and 2013 from the image of land-use maps in 1987 and 2001, which were compared to reference maps for the same dates.

The overall accuracy exceeds 91% and the Kappa index is around 0.90, thus confirming the good fit of the predicted results and model calibration. These values tend to decrease slightly in 2013 to reach 88.97% marking the loss of accuracy for slightly longer predictive periods.

The creation of two confusion matrices, respectively for 2005 and 2013 and their comparison with the reference maps for the same dates shows that overall errors remain minimal. For 2005, 7377 pixels corresponding to farmland have been transformed into forest, in the same way over 13015 pixels in the building category were included in the farmland category. Part of the grassland surfaces (6841 pixels) is

classified as forest category. Overall, urban extension is more concentrated along the coast with a low thrust to the south in the area of the Bay of Algiers.

For 2013, the error is slightly higher. Indeed, 18950 pixels of the forest category were categorized as meadow. The rate of confusion of farmland and building in the forest varies between 7000 and 7400 pixels. Finally, the number of building pixels confused with farmland is relatively low (3726). The model validation is based on the comparison of simulated and real maps obtained by remote sensing treatment for a given date. The Kappa index [29] permit us the comparison between these two maps coupled with the ROC index. The calculation of the index concerned the entire studied zone

The Kappa index of 0.88 and the ROC for different factors is up to 0.80. The Kappa value is relatively lower than for 2005, which suggests the effect of the time interval prediction slightly reduces the accuracy of the result. Strong urban growth is recorded on both the portion of the heights of Algiers and in the eastern sector of the department. This movement is also amplified south towards Algiers airport and along the main large motorway.

Different categories of land-use show a relatively dynamic contrast. Indeed, forests, farmland and meadows recorded a relatively moderate increase between 2013 and 2020 and a very high increase between 2013 and 2030 (Table 3) (Figures 6 and 7). This statement confirms the land crisis that the department of Algiers will face and the acceleration of the urbanization process. Indeed, predictive modelling shows that nearly 80% of the territory of the county will be urbanized. A small proportion of farmland will however be spared in the south-east of the department due to the presence of the international airport which is a constraint and the weak development of the road network.

	Land-use			Evolution (Km ²)		Rate of evolution (km ² /year)
	2013	2020	2030	2013-2020	2013-2030	2013-2020
Forests	188.17	182.67	170.91	-5.49	-11.77	-0.78
Building	242.19	327.93	380.75	85.75	52.82	12.25
Farmland	210.34	194.96	163.72	-15.38	-31.24	-2.2
Fallow	73.9	69.96	59.99	-3.94	-9.97	-0.56

Table 3: Surface changes of different categories over the period 2013-2030.

The main foci with high pressure on land: The Algiers sector shows strong pressure on land starting in the late 70s and being amplified with the massive exodus from the center of the country during the so-called "black decade" period. This phenomenon is reflected spatially by the development of urban centers of varying sizes along the southern arc of the Mitija. It follows overall the axis passing south of the Algiers hills. Nevertheless, and by applying the "Trend" function of Idrisi, two sectors of high urban pressure are clearly identified: one on the Algiers heights marked by regained interest in the hill country despite the topographical constraints (steep slope) (Figure 8).

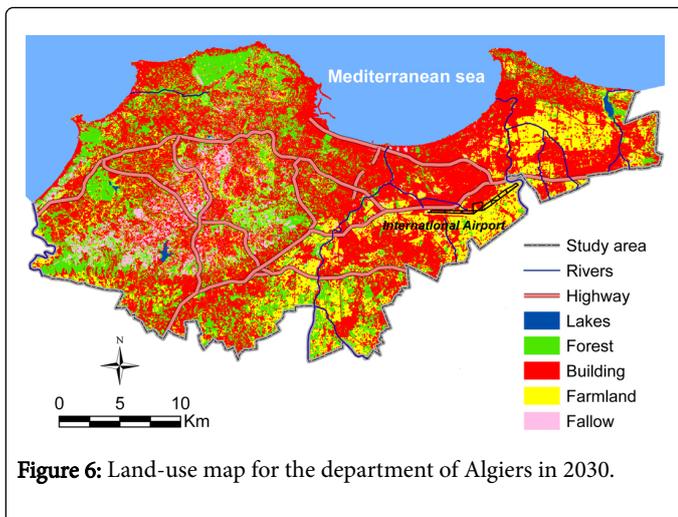


Figure 6: Land-use map for the department of Algiers in 2030.

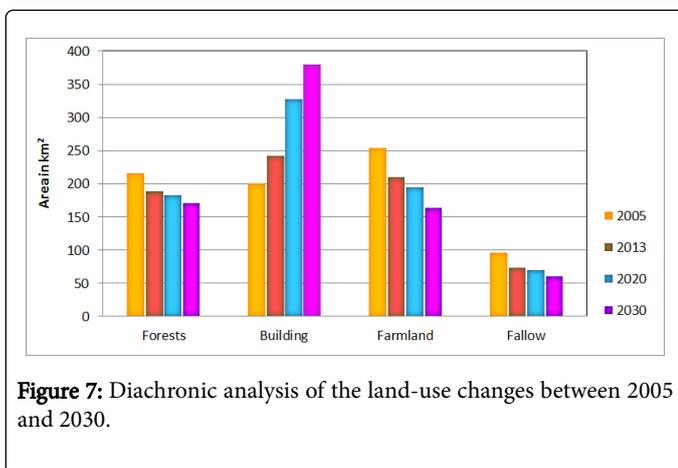


Figure 7: Diachronic analysis of the land-use changes between 2005 and 2030.

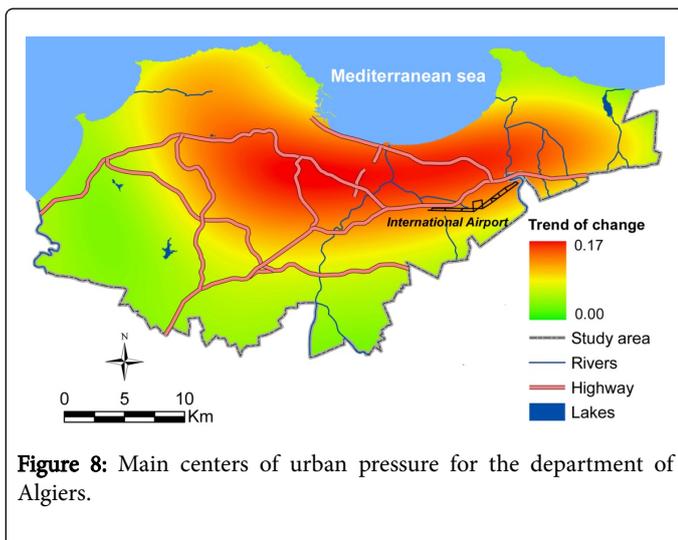


Figure 8: Main centers of urban pressure for the department of Algiers.

The distance factor to the sea is certainly less but an easterly aspect and a view of the sea are two key factors in the choice of real estate sites.

The second pressured site is located near the industrial area of Rouiba-Reghaia marked by low slopes, the proximity to the sea and urban areas of the colonial period. However, this area remains limited

to the south by the presence of Algiers airport, which is a barrier to extension and therefore to the consumption of agricultural land still under cultivation in the south to the foothills of Blida.

Conclusion

The waterfront cities of North African sea-board have seen their farmland reduce rapidly under the pressure of urbanization. This phenomenon has seriously exacerbated the threat of an outright loss of farmland. The department of Algiers, like other northern cities, is a perfect example of the urban dynamics which are also experienced by major cities of northern Africa, and clearly reflects the phenomenon of changing landscape and the replacement of agricultural areas by construction. This process began thirty years ago, first as the effect of population movement from south to north, closer to the major economic centers which accelerated during the so-called "black decade" period.

To try to evaluate these changes, a cartographic analysis was first carried out by using satellite images and comparative analysis of both visual and statistical data over the period 1987-2013. The Kappa index is relatively high (>0.86) and the degree of accuracy is of the order of 90%. Several factors explain this rapid change of land-use including the nearby buildings, land availability, slope, proximity to the sea and especially the density of the road network. All these variables show good correlation coefficients with the categories of land and are therefore considered as explanatory variables to be included in the process of predictive modelling of the evolution of land-use until 2030.

The modelling results confirm the general tendency and the rapid expansion of built surfaces at the expense of agricultural land and secondly forests, largely located on the hills around Algiers. It is distinguished by a pronounced topographical character (strong slope) which was initially a constraint and which in recent years has its space reduced under urban pressure. In fact, the topography (slope) is a less relevant factor than the proximity to the sea.

This change in land-use has been amply reinforced by the development of a road network and moreover transport links split the department into two blocks, one in the north marked by a very high density of buildings especially in the Algiers sector and the other to the south with the emergence of mid-sized urban poles distributed throughout the arc of the Algiers hills.

The general tendency of land-use in 2030 shows two pressure zones: one located on the heights of Algiers and the other at the mouth of the Mitidja plain. This area has a strong agricultural character where vegetable crops dominate and is distinguished by a loose topography. This space is limited, however, to the south, by Algiers airport, which is a rigid barrier and limits urban extension towards the Atlas Blida Mountains.

It is important to note that in dealing with these urban dynamics, the department of Algiers is entering gradually into a land crisis and will quickly face a shortage of land especially for agriculture if no form of organization and control is set up. This extension could in the medium and long term continue towards the Blida Mountains where the stigma of this phenomenon can be seen in particular on the highlands of Meftah. Unlike cellular automats, the Markov method does not take into account spatial dimensions, which makes it less valid in comparison with the former.

However, it is difficult to give more credit to this type of modelling because it fails to take into account certain social factors, which

sometimes leads to situations not being pointed up by this kind of modelling. Thus, contrary to what happens in developed countries, the ban on occupying floodplains is not respected. In the same way, construction in risky areas and those on steep slopes does not constitute a major constraint.

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