"You can tell whether a man is clever by his answers.
You can tell whether a man is wise by his questions".
Naguib Mahfouz

TRAPPED BETWEEN ANTIQUITY AND URBANISM – A MULTI-CRITERIA ASSESSMENT MODEL OF THE GREATER CAIRO METROPOLITAN AREA

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Abstract

This paper attempts to provide systematic policy information regarding land-use/land-cover change in the vicinity of the Giza Pyramids in Egypt. As a result of the rapid urban growth Cairo has experienced in the last couple of decades, a surrounding enclave of urban development seems to be forming around the Pyramids and the highly-valued historical legacy of the area, designated in 1979 as a World Heritage site.

Hence, assessing land-use changes and future urban sprawl prediction is of major importance for strategic planning and avoiding further endangerment. The data used in this study are derived from remote sensing imagery, taken by Landsat TM satellite on 31 August 1972 and on 20 September 1984 and Landsat ETM+ imagery from 11 November 2000. The use of the different bands of that imagery allowed the classification of the land-cover classes: Urban, Vegetation, Desert, and Water.

A temporal comparison of the different types of landcover indicates which land-use changes that have occurred over the years considered are associated with the potential for endangering the Giza complex in the study area.

Keywords: Land use change, cultural heritage endangerment, Giza pyramids, urban growth, Landsat imagery

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1. Study Area and Satellite Imagery

Although relations between Western culture and Egypt date back to Roman history, in more modern times, a well-known appreciation of the grandeur of Egypt and its pyramids was Napoleon Bonaparte's declaration to his troops on 17 July 1798: "*Soldiers! From the heights of these pyramids, forty centuries are looking down on you*".

The magnificent pyramids of Giza and their pyramid complex are located about 25 km from Cairo and comprise the pyramids of Khufu, Khafre, and Menkaure. To the east of the pyramid of Khufu, the Sphinx glares protectively at the pyramid complex which encompasses much more than just the pyramids, that is, the ever expanding metropolis of Al Qahirah (meaning 'the triumphant') near Cairo – the capital of Egypt and most populous city in the African continent. With a population of approximate to 16.25 million (Demographia, 2008) urban sprawl and growth is evident, and between 1994 and 2001 was estimated to be 2.1%.

The Greater Cairo Metropolitan Area (GCMA) includes two cities, Cairo and Giza, and is spatially distributed over three governorates: Cairo (Al Qahirah), Giza (Al Jizah) and Qaliubiah (Al Qalyubyah), while the Greater Cairo Metropolitan Region (GCMR) contains the cities of Cairo, Giza, Shbura El Kheima, five small towns, ten villages and various contiguous suburban and agricultural areas. There are also five satellite towns: the Tenth of Ramadan, Sixth of October, Obur, Fifteenth of May, and Asalam, which are located adjacent to the boundary of the region but not included (El Araby, 2002).

The significant population growth of the city as well as the emerging pollution and landscape change, call for rigorous monitoring of the cultural endangerment resulting from urban growth caused by the adoption of typical European urban land management models in the African continent (Fekade, 2000). Urban sprawl and rapid population growth are an unavoidable reality which often undermines policy towards land use (Veldkamp and Fresco) and the preservation of highly-valued cultural heritage (Vaz and Nijkamp, 2008). A good example of such a landscape is the pyramids of Giza, which were designated as a World Heritage site by UNESCO in 1979.

Urban growth has been a widespread phenomenon in the world in recent times. It can be defined as the "physical pattern of low-density expansion of large urban areas, under market conditions, mainly into the surrounding agricultural areas." (EEA Report

10/2006). The importance of acknowledging the geographical phenomenon of urban sprawl became clear in the European Spatial Development Perspective where the management of cultural and natural resources was one of the key topics of discussion: "*Natural and cultural heritage in the EU is endangered by economic and social modernization processes. European cultural landscapes, cities and towns, as well as a variety of natural and historic monuments [,] are part of the European heritage. Its fostering should be an important task for modern architecture, urban and landscape planning in all regions of the EU.*" (ESDP, 1999, p.10). Although this argument represents a European version of the dichotomy of urban growth versus the preservation of cultural heritage, Harisson et al. (2008) outline the need for a collective sense of the past, lending it a more global character in which lessons of preservation may be learned for future generations. Cairo has experienced massive urban expansion for demographic, economic and political reasons and this remains nowadays an undoubtable challenge of modernity (Yousry and Atta, 1997).

The tension between those two realities is typical of the confrontation between modernity and the cultural legacy at regional level. It has clear spatial attributes and often divergent interests, which have to be regulated in the interests of sustainability. As sustainability becomes a spatial issue with regional inputs, Geographic Information Systems (GIS) can measure the dynamic aspects of spatial decision making and enable stakeholders to make the best decisions (Gadal, 2006).

The study area is located at around latitude 29º 58' N, longitude 31º 07' E, and the corresponding reference of path/row for Landsat was 176 / 39. Satellite imagery, freely downloaded from the Global Land-Cover Facility (GLCF) allowed for a classification of the four main land-cover classes (urban, vegetation, desert, and water), while at the same time enabling land use changes to be monitored over the relevant period.

A limited amount of research has already been performed based on the spatial perception of urban growth in the vicinity of Cairo. This paper has as its main objective the development of an urban growth simulation experiment to explore the context of cultural heritage endangerment by using remote sensing imagery.

By considering urban growth in the different governorates that constitute the GCMA, Multi-Criteria Evaluation (MCE) and predictive scenarios of land-use change will allow the definition of those aspects that contribute broadly to environmental and cultural degradation. These issues merge into a conflict between urban development and socio-economic considerations that are crucial for stakeholders.

The scenarios of urban growth are also reviewed in a predictive context, in the hope of identifying factors which are directly related to the urban growth which now imperils the pyramid complex of Giza. For this, the use of remote sensing imagery is foreseen in order to create land-cover maps of the study area. The assessment and quantification of the degree of urbanisation of the land-cover maps, as well as the consideration of other important variables such as slope, elevation and urban proximity, will allow the recognition of land-use change for future scenarios.

Our paper thus has several dimensions of scientific and policy interest:

- The development of land-cover scenarios for the region based on freely downloadable satellite imagery of Landsat satellites, which suggests that low budget resources may play an important role in understanding the environmental and urban dynamics from a spatial perspective.
- The creation of simulated suitability maps showing urban tendencies in the various parts of the GCMA.
- Understanding the dilemma of cultural heritage endangerment due to urban growth and environmental degradation in large populated cities with the main focus on tourism.

2. Methodology

Figure 1 represents the development of the methodology for the creation of land use classes. Image classification presupposes the categorization of Landsat imagery pixels into clearly defined land-cover classes. In this context, Landsat satellite imagery has been shown to provide accurate data for spatio-temporal analysis (Bédard et al., 2007). The process of supervised classification[1] consists of three steps: (1) identifying training sites, representing areas, and developing a numerical description of the electromagnetic spectrum attributes, (2) classification of each pixel in the image into a land-cover class; and (3) production of thematic maps showing land-cover in the study area (Lillesand et

[1] This is a classification function that predicts output results based on selected input attributes chosen manually by the user.

al., 2004). The creation of land-use maps due to advances in satellite image receptors and their application/use allows us with some accuracy to observe land use changes at different moments in time. This is particularly the case in regions which have not previously been intensively and regularly mapped, leading to the development of scientific methodologies for land-cover analysis and the development of topographic maps. In the process of generating land-cover, they are validated by geo-referencing vector points onto Google Earth. The novelty of this approach, contrary to common validation methodologies based on topographic 1:100000 maps, is essentially based on the interest of analysing the low budget possibilities of land-use change in an attempt to deliver an ‘available to many’ scientific approach to spatial environmental analysis. Therefore, satellite imagery data was downloaded from the Global Land-Cover Facility (http://www.land-cover.org/index.shtml). This data is available for download for Landsat MS, TM and ETM+ satellites.

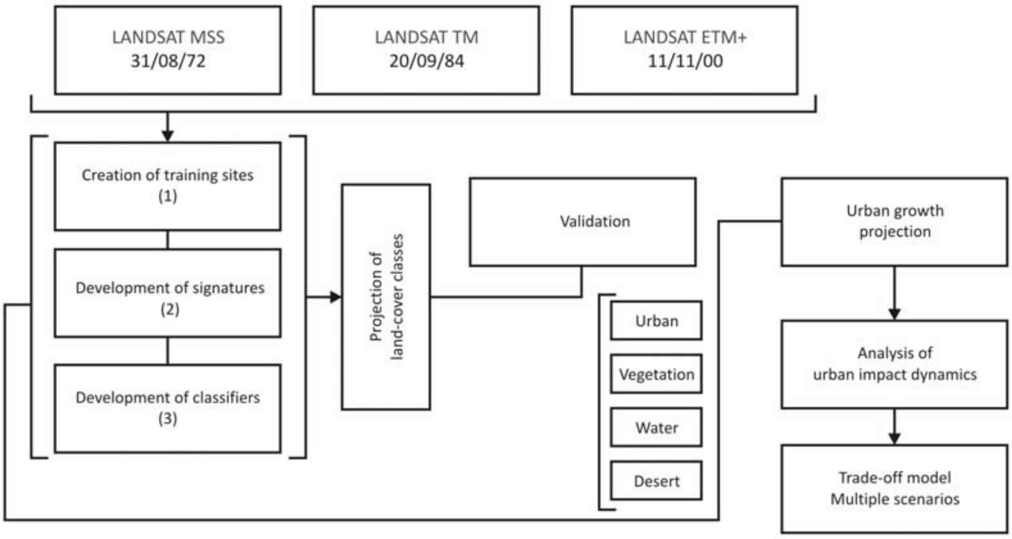

Figure 1 – Methodology for the creation of land-cover classes

Once our subsets of classes are validated, urban growth will be projected based on suitability maps derived from the results of MCE.

The maps generated by MCE allow stakeholders to have the possibility of analysing multiple alternative scenarios which represent trade-offs of different strategic options. The existence of multiple choice possibilities (or alternatives) represented by different scenarios is the very essence of MCE, where the various alternatives are evaluated on the basis of a series of conflicting and incommensurate criteria (Malczewski, 1999). Our approach is based on a weighted ranking procedure.

This approach is supported on a generated suitability map which is then spatially analysed by the stochastic comparison of urban change in the different generated land-use maps. Artificially constructed (i.e. urban) areas will assemble the weight factor of each of the multi-criteria variables in the analysis. By cross-tabulating this information with derived socio-economic data such as employment per region of the GCR, we will then assemble multi-choice scenarios which allow stakeholders to identify the best possible strategic choices in connection with the following dilemmas: More/less Tourism; Employment and urban growth challenges; Cultural heritage endangerment vs employment and tourism.

3. Comparing Types of Land-covers

The suggested methodology allows the identification of various types of land-use cover with high accuracy. Thus, 1972, 1984 and 2000 land-cover maps are obtained from the raw image data of the Landsat MMS, TM and ETM+ data.

The combination of available electromagnetic spectrum ranges allowed the application of minimum distance classifiers[2]. Based on the existing land-use classes of urban, vegetation, water and desert, a combination of Red (Band 3), Green (Band 2) and Blue (Band 1) was chosen. The creation of vector training sites with clear land-cover classes allowed the development of signatures which led to the creation of the classifiers. The classification stage consists of categorizing each pixel in the image data set into the land-cover class it most closely resembles.

Land Use and Land-Cover Change (LUCC) models are important tools for the appraisal of environmental change because of their capability to quantify human aspects of environmental dynamics, which is of growing importance in identifying the subtleties of the rural versus urban dichotomy (Lambin et al., 2001). LUCC models tend to become,

[2] This concerns a supervised classification method based on the creation of a multidimensional space defining distinct classes of land-cover. The pixels are assigned in the classification process to the closest land-cover class.

therefore, multi-agent systems which allow inference to be made about the quantitative effects of land-use change derived from the application of econometric and statistical tests (Parker et al., 2003).

Figure 2(a) below shows the exact location of the study area in the GCMA and the temporal comparison of the extrapolated types of urban land-cover from the satellite imagery. Pixel quantification allowed the generation of temporal strata which led to a dynamic comparison of the evolution of urbanism (see the trend graph in Figure 2(b)). This allows us to conclude that, although urban growth has been continuous over the three decades covered by our observed spatial assessment, the evolution of urban growth in the governorates is not constant, as each of the three governorates clearly present a distinct path of urban growth. For instance, the governorate of Al Qalyubyah seems to expand much more rapidly than Al Jizah or even the main Governorate of Al Qahirah. In contrast to what might have been expected, Al Qahirah with the highest amount of built-up land at the beginning of the 1970s, has experienced the lowest urban growth in the following 30 years. Furthermore, for all three areas urban growth seems to be especially significant between 1984 and 2000.

The apparent inexplicable differences in urban growth in the different governorates around the periphery of the capital create an interesting opportunity for multi-variant decision making by the use of Multi-Criteria Analysis. As policies may vary in a context of economic, social and environmental perception and hence, influence urban growth, our research agenda covered the following phenomena: (1) tourism growth among the governorates by measuring both hotel density and the regions' attractiveness in terms of cultural heritage provision per governorate; and (2) population trends by the analysis of population growth within the boundaries of the governorates. Comprehension of these intertwining aspects requires multi-criteria decision rules which allow the quantification of what particular factors have a higher or lower weight in the development of urbanism in the study area.

Defining the future trends of all these specific dimensions will contribute to a more profound understanding of the direct impacts of tourism and/or socio-economic factors on cultural heritage.

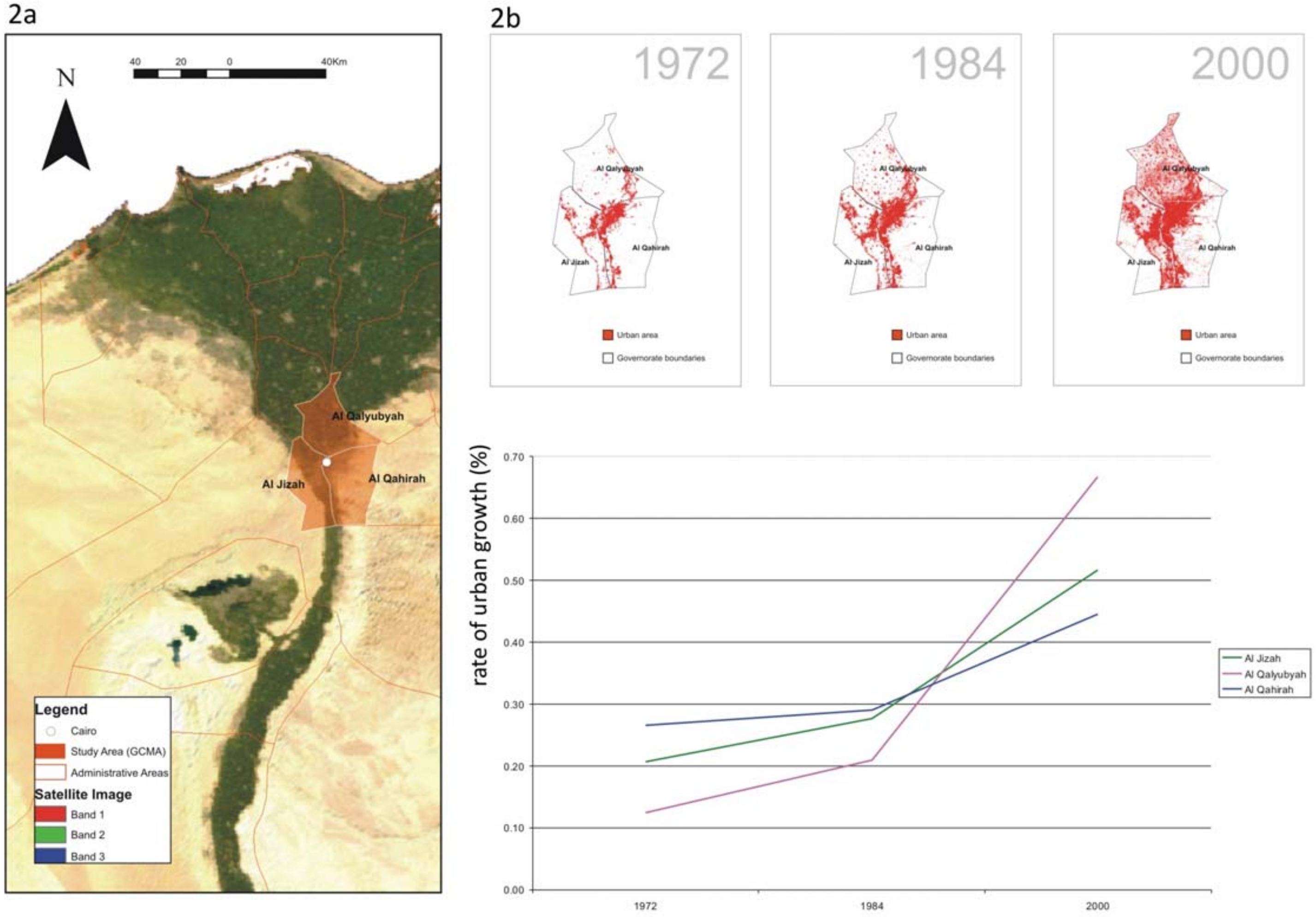

Figure 2 – (a) Study area and (b) urban growth comparison

4. Modelling Urban Growth in Cairo

LUCC modelling presupposes implicit but systematic knowledge of the explanatory variables or drivers of urban growth. As suitability maps represent a synthesis of different variables, they become of utmost importance for identifying and imposing critical weights which add to changes in land use. High values on the generated suitability maps indicate a higher propensity for the existence of a specific type of land use, while a lower propensity represents a lower tendency for land use change in these areas. The matrices generated by the GIS-engendered raster format allow a multi-criteria evaluation system which imports different sets of explanatory variables, including contextual variables and policy developments (Voogd, 1983).

4.1 LUCC and satellite imagery interaction

The information content of the LUCC model, combined with raw Remote Sensing data sets, offers therefore a unique chemistry to explore the possibilities of quantifying future land-use scenarios. Figure 3 illustrates how the projection of present outcomes on LUCC (2008) is based on the previously extrapolated land use data. By filtering the projected 2008 data, artificial (urban) land use developments may be derived and next compared with, for instance, a future LUCC scenario of 2038. The comparison of both new time frames establishes the relation between the consequences of future land use in the context of a multi-criteria analysis, in which a variety of policy-relevant variables are considered in order to assess the overall endangerment in the Cairo region.

Acquiring spatial knowledge in a temporal context should allow the creation of predictive models based on weighted initial data. The latter are an outcome of Multi-Criteria Evaluation (MCE) with respect to land-cover defined criteria through statistical methodologies (for example, logistic regression). Additional constraints (e.g. Boolean sets of conditions of restraint) as well as trade-off factors which articulate their influence on a given cell value, concisely express what we may call a suitability map.

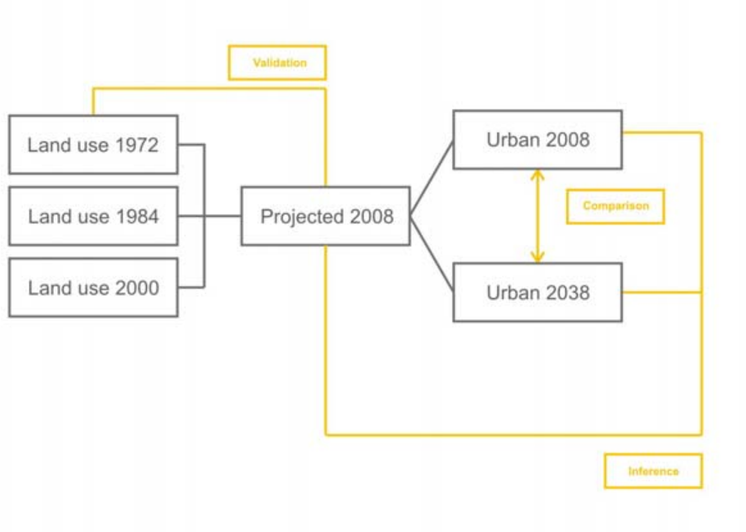

Figure 3 – LUCC relations for urban assessment

4.2 Multi-criteria evaluation for suitability maps

The suitability maps reflect those environmental characteristics which are important for an objective interpretation of future land use scenarios. The propensity for urban growth becomes evident, and may thus be better understood, in a context of urban planning and decision making. Table 1 expresses the factors and constraints for our model, as well as for the derived maps. The choice of the fundamental variables that explain urban growth is based on bibliographic research on the subject, as well as on the common sense of planning strategies and elementary geographical notions. In this context, Hofstee and Brussel (1995) highlight the importance of proximity to the city centre, directly adjoining the previously built-area. Chen et al. (2002) and Clarke and Gaydos (1998) show the intrinsic relation between urban growth and slope derivatives, since areas with a low slope clearly represent less tendency to become built-up (Clarke and Gaydos, 1998; Chen et al., 2002; Vliet et al., 2009).

The weight of each of the variables may be expressed by the following formula:

$$W = [((\text{urban}_{n} + \text{urban}_{n+1}) / \sum(\text{urban}_{n+1} + \text{non-urban}_{n+1}) / (\text{max-urban}_{n+1}))]*100$$

The specification of this model in the form of a combination over the series of classes represents essentially an unrestricted logistic regression over space, of which empirically estimated equations may be derived to fit our suitability map. Table 2 shows the statistical tests (standard deviation, average, t-statistic and R-squared, as well as the final regression model per variable).

Table 1 – Factors for multi-criteria urban growth modelling

Factor	Technical processing	Bibliographic support
Distance from roads	Observed transitions of 1984 and 2000	
Proximity to areas built in 1972	Distance from possible semi-historic urban areas	Hofstee and Brussel
Elevation	Regression factors based on variation of 1984 to 2000 urban growth	
Slope	Regression factors based on variation of 1984 to 2000 urban growth	Chen et al., (2000) Clarke and Gaydos (1998), Vlied et al. (2006)

Table 2 – Statistical tests used for variable weights over space

Factor	Standard deviation (%)	Average (%)	t-statistic (*t*)	R-squared (R^2)	$E(Y) = b_0+b_1X_1+b_2X_2+b_3x_3$
Distance from roads	37.02	38.83	1.15	0.78	$E(Y) = 78.4 + 9x_1 - 1.5x_2 + 0.04x_3$
Proximity to areas built in 1972	33.58	50.27	1.36	0.26	$E(Y) = - 61.2 + 185.3x_1 - 71.9x_2 + 10x_3$
Elevation	8.80	6.37	0.72	0.16	$E(Y) = 183.2 - 94.4x_1 + 21.6x_2 - 2x_3$
Slope	19.49	77.93	4.00	0.69	$E(Y) = 84.6 + 1.7x_1 - 0.1x_2 - 0.0002x_3$

The existing city centre was excluded from the 1972 created land-cover, and Euclidean distances were measured from the perimeter of the central area. Urban sprawl was expected to occur adjacent to existing urban growth, given the laws of urban contiguity and the proximity of previously existing urban areas resulting from existing network and available infrastructures.

The suitability map becomes therefore a synthesis map which allows the simulation of ideal choices of urban growth and is a result of the recognition of independent variables which contribute directly to behaviour of urban growth at the spatial level, and at the same time becoming *"significant for land use planning to exploit potential capacity of land, to increase food production and income with effective use and sustainable development of land"* (Zhou et al., 2005, p. 2426).

Our overall analysis of the suitability map (Figure 4) shows a tendency for future urban growth in peripheral areas, but located relatively near to previously existing urban centres.

The perception of each individual map as a criterion map with specific user-defined weight gives it the characteristics of a multi-criteria decision model (MCDM). Each criterion map is combined with the others, leading to the suitability map with capabilities to predict urban propensity. Constraints and criteria should be very well defined and preferably reflect users' intuition and bibliographic support. The success of the MCDM is a consequence of the extrapolation of the final result of the suitability map and its projection to a known time frame (2008), as is proposed later.

The generated Criterion maps were next reclassified into the scale 0 (minimum propensity) to 255 (maximum propensity) which allowed the comparison of individual values of propensity (Eastman, 2006) and corresponded to a Multi-criteria Evaluation of a Weighted Linear Combination, taking for granted the existing constraints, defined by previously built-up areas and the land-cover classification water, as well as the input criterion factors. Multi-criteria weighting was done by pairwise comparison of factors on a 9 point continuous rating scale with values ranging from 1/9 to 1 (less important: completely unimportant to equally important) and 1 to 9 (more important: equally important to completely important) as proposed by the analytical hierarchy process (AHP) model (Saaty, 1977).

The following relations were established based on these criteria (see Table 3):

Table 3 – Weight criteria for MCE

	Distance from Roads	Slope	Urban change from 1984	Elevation	***Eigenvectors***
Distance from Roads	1				0.1454
Slope	1/3	1			0.0706
Urban change from 1984	3	5	1		0.2929
Elevation	3	4	3	1	0.4910

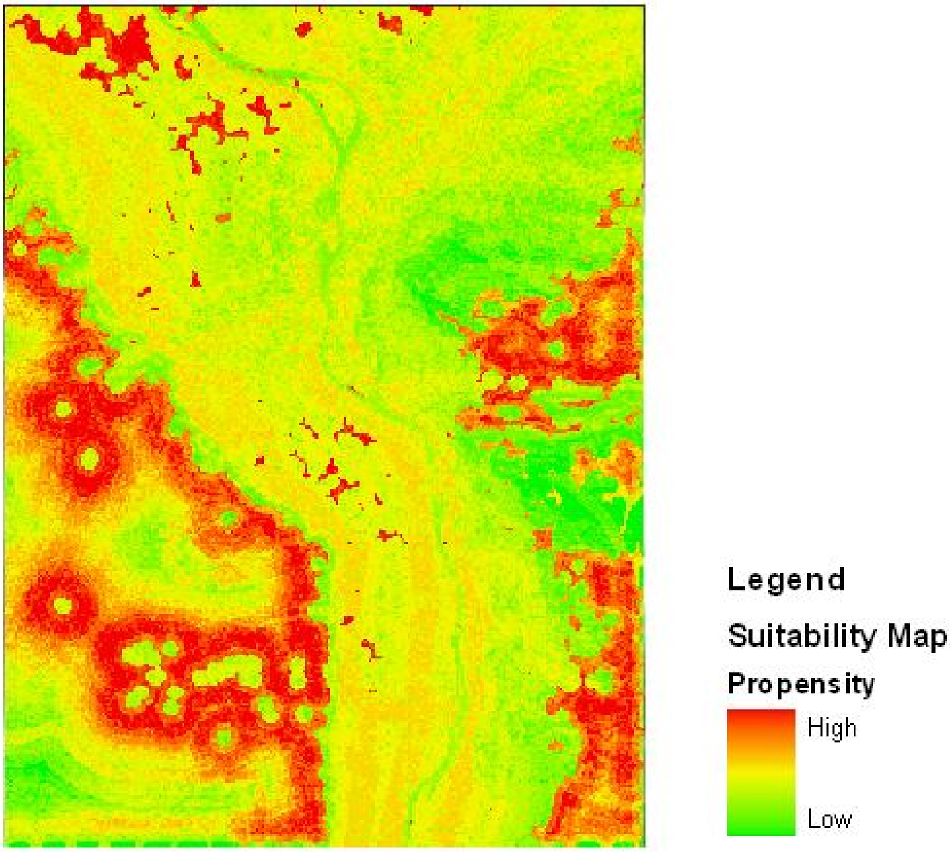

Figure 4 – Suitability map and propensity for urban growth

Eigenvectors were generated based on the existing weights in order to establish a comparative factor weight for each of the independent variables, with a consistency ratio of 0.09 which is acceptable for the purpose.

The results clearly show the importance of urban change and urban proximity and elevation while attributing some weight to distance from roads and less in this case to slope (as we noted previously, there was little variation in slope in the built-up areas in the studied area, although this variable often has some importance).

Finally, the suitability map was generated on the basis of the inserted eigenvectors in addition to the logistic regression of each variable. The result thus corresponded to a multi-criteria transition assemblage predicting a transition towards urban change for the Cairo study area given by the following equation:

$$\text{Suitability} = (e*f_n)+(e_{n+1}*f_{n+1})+(e_{n+x}*f_{x+1}),$$

where **e** are the calculated eigenvectors for factors and **f** are the factors used.

The suitability map detected a tendency for the growth of urban sprawl outside the original city perimeter. A strong tendency for a denser urban area seems apparent on the western side of the GCMA, while to the east, in the Governorate of Al-Giza, the formations of 1972-1984 urban nuclei have become seeds for sprawling urban development.

Construction in the desert might occur less, but the substitution of vegetation areas by urban use becomes an evident phenomenon. A prominent mass of urban areas appears to occur just north of the Giza Pyramid complex, alerting us to the possible consequences of ongoing urban growth on areas with valuable and vulnerable cultural heritage.

4.3 Transition probabilities and Markov chain analysis

Land-cover knowledge for future land use projection was based on Markov chain analysis which allows land-cover to be compared at two different points in time. Transition from one class can be quantified and gives a clear indication of future land use (Bell, 1974). MCE has been shown to have the capacity to describe LUCC independently of the persistence of certain trends, serving as a rich indicator for future land use projections (Weng, 2002). By means of a transition matrix (Table 4), probabilities of land change are associated with the strength of each cell value.

Table 4 – Markov chain analysis of probability of transition to the various land-cover classes

Cells in:	Expected to transition to:			
	Urban	Vegetation	Water	Desert
Urban	73.85%	14.41%	5.89%	5.85%
Vegetation	34.47%	60.01%	5.52%	0.00%
Water	5.37%	18.04%	76.38%	0.21%
Desert	19.87%	0.00%	0.00%	80.13%

Some interpretation becomes feasible and consistent after converting the generated pixel quantification into a percentage cross-tabular matrix where the rows represent actual cell values and the columns Markov transition propensities.

A clear tendency for urban growth is visible, and changes regarding this specific class primarily involve a change from vegetation to urban areas, followed by further expansion into desert areas. The propensity for water areas to change use into urban seems unlikely, and the 5.37 per cent value may be explained by a misapproximation resulting from the created land-cover. Nevertheless, this value does not hinder the correct assessment of urban growth, as the presence of water is used as a constraint in the projection scenarios projected for 2008 and 2038.

4.4 Use of Cellular Automata for projecting urban growth

Urban growth projection for 2008 (Figure 5) was achieved by combining the probability transition matrix calculated by MCA and the suitability map (representing the calculated logistic regression factors) and constraints (water areas and existing urban areas in 1984). This hypothetical transition served as the starting point to generate a Cellular Automaton which encapsulated the suitability map and the relative propensities of urban growth, as well as the probability matrix of land class changes in land use maps (Clarke and Hoppen, 1997). The result is a projected land-cover for 2008 which must be assessed on ground truth[3]. The low availability of technical topographic data for the study area requires the construction of a comparison method with available imagery.

In the next step, 100 vector points were randomly distributed among the defined 2008 urban areas and projected onto Google Earth™ for validation. This allowed assessment of the adequacy of modelled urban growth onto a ground truth surface. The measure of agreement for urban areas is indicative of the global accuracy of the 2008 projection and the validity of urban prediction. Our global validity is demonstrated by 176 correctly classified vector points as opposed to 24 wrongly classified (see Table 5). The achievement of a global accuracy of 88 per cent allowed us to further project the urban growth model to a potential 2038 scenario, if policies are kept stable in the coming 30 years.

Table 5 – Global accuracy of urban projection in 2008

	Correctly Classified	Wrongly Classified	Total
Urban	176	24	200
Percentage	88%	12%	100%

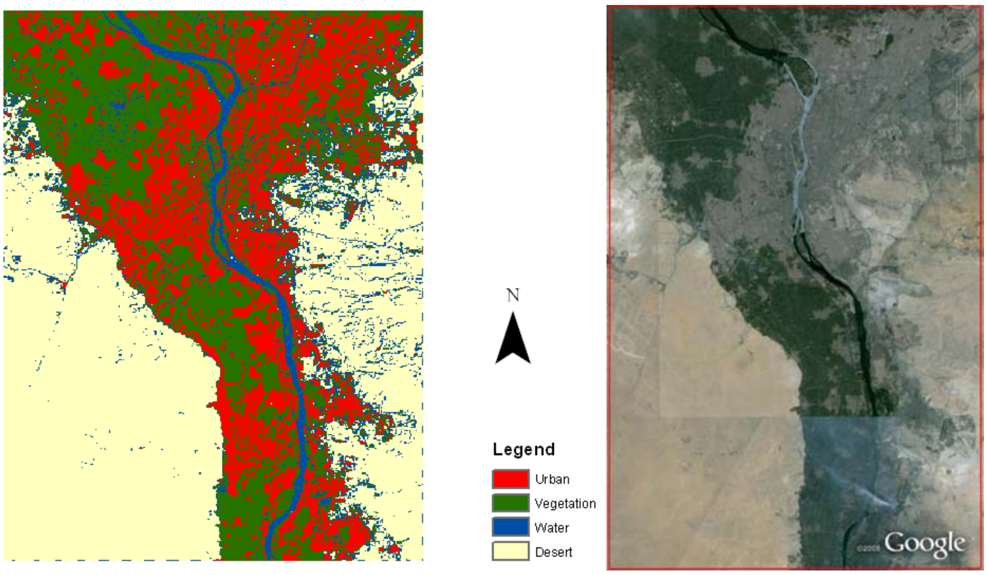

Figure 5 – Projected 2008 urban area and high spatial resolution Google Earth™ correspondence

[3] This term is used in cartography, meteorology and remote sensing and corresponds to the information collected on location or from an aerial photo with a more accurate perception of reality.

5. Projecting Urban Growth for 2038

The chosen criteria of slope, elevation, urban proximity and road distance seemed to be adequate to project urban growth for 2008 as proved by the spatial validity of the modelled land-cover. Uncertainty in urban projection is a permanent problem, as urban growth will necessarily be dependent on developments caused by politics, policies and stakeholders. The visualization of future scenarios is, 0therefore, a result of the hypothetical interpretation of future occurrences, and should only be seen as an informative support to decision making and not as an accurate predictive truth (Paegelow and Olmedo, 2005). The accuracy of results for 2008 allowed us to project a future scenario based on the same factors and constraints, where constraints now represented the derived water and urban coverage for 2000. Probability changes were measured based on the comparison of Markov transitions between 2000 and 2008, and by then projecting the probability of land-use change for 2038. The result is depicted in Figure 6 below. As we may observe, there is a clear tendency for loss of vegetation areas. However, even though vegetation continues to be occupied by urban areas, some vegetation areas should for ecological reasons remain intact in the next 30 years. An example of this is the beautiful vegetation area located northeast of the pyramid of Khufu in the vicinity of the village Nazlet el Samman. This specific vegetation area supports the existence of the popular Mena House Oberoi Golf course. Allowing co-existence of tourism and sustainability of cultural heritage, this location does not have to change in the forthcoming years until 2038. This shows that in terms of urban planning touristic infrastructures may be envisaged for integrating sustainable options, so that further planning initiatives dealing with this question might be considered.

It is expected that the village of Nazlet el Samman will continue to grow further because of its proximity to the dominant traditional urban areas and to road networks. Northern Giza seems to be expanding rapidly, as new buildings and complexes, developed at the beginning of 2000 with the creation of subsidiary roadworks, seem to create by 2038 an even greater urban growth. These new urban areas are now generating

– and will be expected in future to encompass – an even broader and denser area surrounding, for instance, the pyramid complex of Giza.

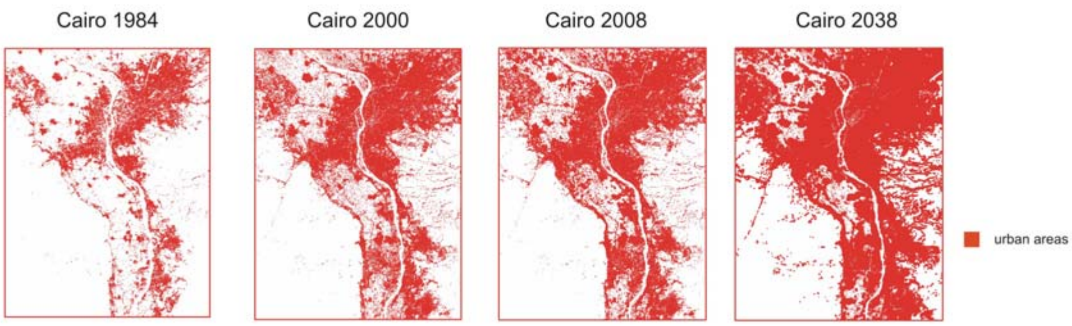

Figure 6 – Urban growth projection for 2038

6. Conclusions

In the coming decades, the delicate nature of cultural heritage around the GCMA, such as the different pyramid complexes and in particular the pyramid complex of Giza, could be in imminent danger because of the rapid expansion of urban growth. By 2038, it is expected that the pyramid complex of Giza in Cairo may be completely engulfed by the glass and concrete infrastructures of 21st century urban growth. By analysing satellite imagery and creating land-cover maps for this specific area, our study demonstrated that it was possible to obtain a broader view on the concept of spatial urban growth in a World Heritage site.

Figure 7 maps out the various methodological stages of our research. While Figure 7 represents the overall process of understanding urban growth, its complexity should be assessed in the context of trade-off opportunities which may arise from economic, social and political conditions. As the three governorates concerned may develop different strategies, options regarding the growth of a mass tourist industry which has excelled in the region since the beginning of the 20th century, should be articulated with global concerns on the imminent vulnerability of cultural heritage.

The remarkable tendency for urban sprawl in the area since the 1980s shows the link between classifications of world heritage and the unpredictable consequences of having heritage tourism attractions in the long run. Population increase in Egypt has been in evidence since the last 50 years, but, nevertheless, it is with the creation of tourist infrastructures which provide proximity to tourist attractions that urban spatial sprawl is induced and becomes even denser until the beginning of 2008.

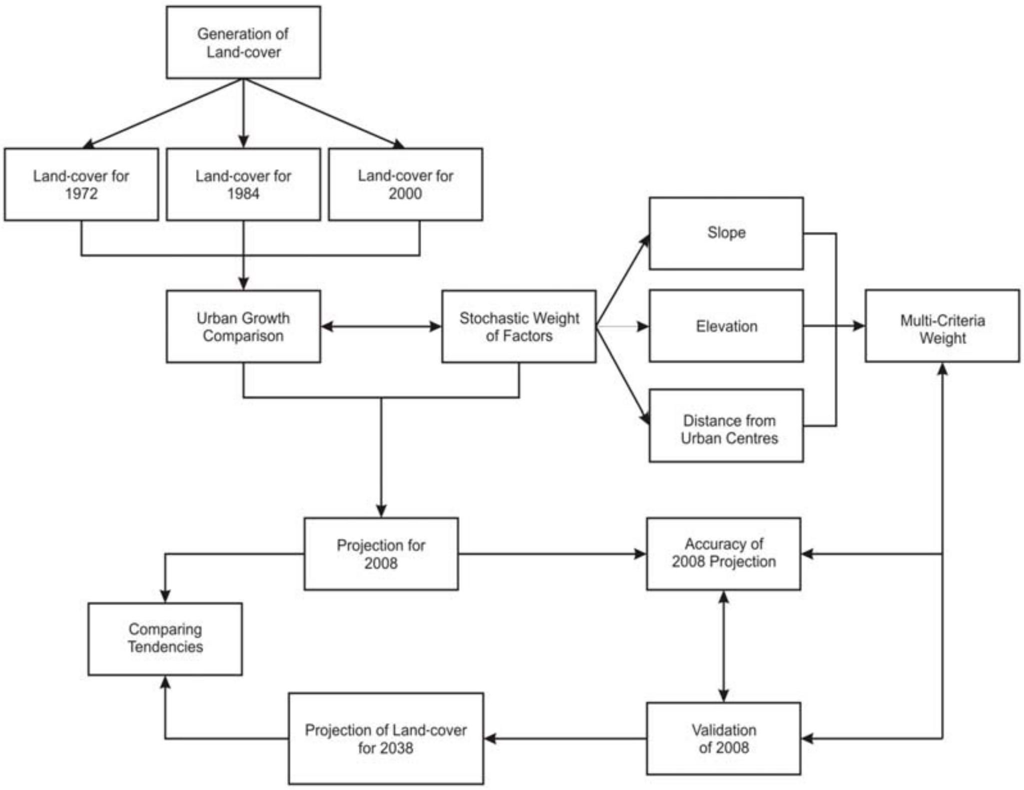

Figure 7 – Methodology for Urban Growth Assessment

It has become clear that satellite imagery may become an important tool for the assessment of World Heritage sites, and those proactive measures should be taken seriously to avoid endangerment of fragile artificial heritage.

Urban growth may in the medium run be a pernicious consequence leading to unavoidable harm due to pollution and land change at the expense of valuable cultural heritage. The analysis of future urban scenarios has also shown that new construction in the area of the pyramid complex of Giza shows the creation of new networks and new infrastructures in which urban development tends to use tourist attraction as a way to explore the possibility of future urban growth.

The objective of this study has brought to attention – besides the potential of the use of satellite imagery for heritage perception and preservation in less geographically studied areas – the importance of heritage preservation and the assessment of urban growth, on which future work should focus as the key factors of economico-environmental sustainability based on knowledge of those pollution and destructive factors which directly influence the land use and environmental changes in a given area. Regional knowledge is intrinsic to spatial understanding (Massey, 1979), and this justifies the computation of spatial models as important tools for urban and planning sciences. From this perspective, local knowledge of the trade-off factors that influence spatial contexts, such as environment and cultural heritage, seems an important asset which allows more accurate sustainability policies.

Figure 8 shows the multi-criteria process involved in constructing the architecture of the possible relations involved in choices concerning future land occupation, social and governance choices and policies. Though we have analysed the complexity of urban growth in the context of stochastic probabilities, and hence, have predicted future urban occupancy, in addition Multi-Criteria Evaluation (MCE) may be seen as a very effective tool for land use analysis (Beinat and Nijkamp, 1998). It shows the implications of different choices in a toolbox of effective decision-making which combines MCE with spatial analysis methodologies and GIS, as was exemplified by the integration of spatial decision support systems. This also highlights, in a context of both social, political, and economic trade-offs and governance fragmentation, the intrinsic environmental complexity for regional decision making.

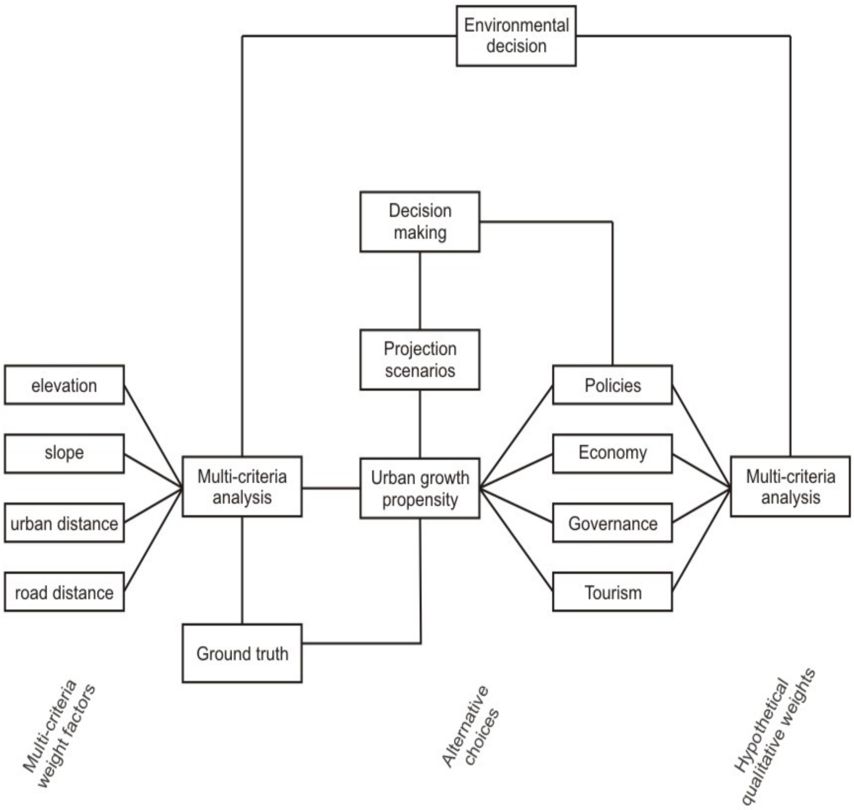

Figure 8 – Spatial and regional complexity for environmental decision making

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