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Driving Forces and Future Directions of Informal Urban Expansion in Greater Cairo Metropolitan Region.

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カイロ大都市圏における都市スプロール化の要因と予測に関する研究

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June 2016

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A dissertation submitted by

Taher Mohamed Khamis Osman

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Summary

This research examines the issue of the Informal Urban Expansion (IUE) in agricultural lands in the Greater Cairo Metropolitan Region (GCMR). In GCMR the Informal Urban Expansion phenomenon is expected to accelerate in the next several decades, which will lead to crowding, housing shortages, insufficient infrastructure, and worsening urban climatic conditions. Since the 1950s, Egypt has witnessed a rapid urbanization in the form of expanding residential, industrial, and commercial activities around major cities. Unplanned residential areas accommodate between 12 and 17 million inhabitants or about 40-50% of Egypt's urban population. Despite 30 years of effort by the government to manage this phenomenon, unplanned settlements around the Greater Cairo Metropolitan Region (GCMR) become the home for more than 7 million people by 1998. Unplanned residential areas in GCMR were home for more than 65% of the total GCMR population in 2006. And research based on satellite images have indicated that the surface area of unplanned settlements in GCMR expanded by 3.4% per annum between 1991 and 1998. This expansion deteriorated the built environment and had a negative socioeconomic impact. On the other hand, urbanization supports socioeconomic development and improvements in the quality of life. This demands a system to manage negative impacts of rapid urbanization.

There has been a growing interest in identifying the impact of IUE and its driving factors to develop successful urban plans and management policies in developing countries. In the context of Egyptian urban planning, developing decision support tools for policy analysis, scenario building, and prediction in the early stages of land-use planning requires new research. This research intends to fill the need for research that explores the relationship between existing policies and future growth trends. Dynamic modeling of interactions between IUE and its driving forces can provide a step forward for decision-making and, analyzing appropriate policy interventions. In this research, we focused on Giza Governorate (the western part of GCMR) as a cases study, to analyze and understand the nature of IUE. It also studies the driving forces of IUE and their influences. The specific objectives of this research were: 1) Identifying the influence of government housing policies on IUE and on low-income housing; 2) developing a spatial indices to quantify and analyze spatial-temporal patterns of IUE; 3) Exploring socio-economic and physical driving forces of IUE and their influences; 4) And assessing consequences of different policy interventions on future IUE patterns and potential risk to agricultural lands.

Chapter 1 provides the rationale of the research topic and its scientific and social relevance. Then, it defines the research objectives, the study area and provides an outline of the thesis. Chapter 2 discusses the nature of the housing policies and their relationship to housing issues. Primary data for this study was derived from a questionnaire survey. The analysis results revealed that the existing policies have failed to end the phenomenon of IUE of low-income residential areas. The housing policies were not effective enough to meet the urban housing demand among young generation creating an accelerated growth of IUE. Chapter 3 examines the nature of IUE on current literature. Then, it quantifies and analyzes the spatial and temporal patterns of IUE using remote sensing data from 2004 to 2013. The results revealed the rapid expansion of IUE in Giza Governorate and its spatial characteristics. Following attributes of IUE were observed; fragmentation and unevenness of landscape, discontinuous development, strip development, leapfrog development, low density of land use growth, low population density.

Chapter 4 explored the physical driving forces and their influences on IUE by applying Logistic regression model. The findings of this study demonstrated the decreasing significance of the CBD and Nile River and the increasing significance of local urban centers on IUE. Moreover, we found that accessibility factors, especially neighborhood factors have a significant. The study area will experience urban expansion around existing IUE locations in

the future. In Chapter 5 a questionnaire survey was conducted among planning professionals to identify the socio-economic driving forces of IUE and to analyze their relative influence within Giza Governorate. The study area was divided into three sectors in this study. The results revealed that current development plans have the lowest significance as a regulating factor of the urban expansion. By contrast, increasing population shows a high significance as a driving factor. Moreover, the results highlighted significant differences in relative significance of driving factors among three sub-sectors. These results highlighted the need for local urban plans that reflects needs of each sector. Current plans ignore such differences and treat the entire governorate as a single unit.

Chapter 6 investigated the consequences of different policy interventions on future IUE patterns and potential risks on agricultural lands. We applied an integrated model based on Markov chain, cellular automata, and logistic regression model to simulate three urban development scenarios namely; historical growth trend (HGT), compact growth (CG) and growth based on official plans (GOP). Under the HGT, and GOP scenarios, the IUE would cover the whole study area in future. IUE will discontinuously expand around major urban areas, or continue along major roads under the CG scenario. The CG scenario was effective in meeting the goal of environment protection. Chapter 7 focused on the middle sector (highly urbanized area near the Giza CBD). This study applied SLEUTH simulation model to investigate three growth scenarios (HGT, CG, and GOP). The results were consistent with the predicted patterns of Markov chain (MC) model. The results showed a highly dispersed development patterns under HGT compared to GOP scenario. The CG scenario constrained the growth in and around major urban centers. These findings are reflecting the effect of flat topography of the area and indicate that the urban development and the agriculture conservation are conflicting goals in Giza environment. The HGT scenario is preferable if the priority is given to urban development. However, the other two scenarios are recommendable if the priority is conserving agriculture lands. Finally, Chapter 8 provides the synthesis of the results and the conclusions of chapters' two to five.

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1. General introduction

1. General introduction

1.1 Background

The world has experienced a dramatic growth of its urban population for over the last 50 years [1], and the rate of the urban population growth is more than that of the rural population [2]. The world's urban population is estimated at 3 billion in 2003, and is expected to rise to 5 billion by 2030 [1], almost two-thirds of the world's population will be living in towns and cities [3]. The speed and scale of this growth have usually been concentrated in developing countries which are characterized by larger metropolitan areas.

Metropolitan areas are expanding in all directions resulting in large-scale urban sprawl and land-use change (LUC). With the development and infrastructure initiatives mostly around the urban centers, the impacts of urban sprawl would be on the environment and the natural resources. A misuse of urban land along with urban sprawl improperly concentrating activities in one region and leaving much waste land, results in environment deterioration problem such as increase of air and water pollution, traffic congestion, shortages in urban services and facilities, and major problems of urban poverty such as lack of housing security, limited opportunity for education [4]. The spatial pattern of such changes is more clearly noticeable on the urban fringes or city peripheral rural areas than in the city Centre. Inadvertently this results in an increase in the built-up area and associated changes in the spatial urban land-use patterns.

Urbanization is the social process whereby cities grow and societies become urbaner. Urbanization is significant all over the world and there are many factors which influence the urbanization like population growth, good prospects for livelihood and availability of facilities [5]. Economic growth and urbanization are linked with each other. Economic growth often guides the conversion into the urban land from rural land. Economic growth of any area depends on the availability of resources. The economy of Egypt was mainly based on agriculture and in that good mineral resources are enhancing the development. The more industrialization matured, the more opportunities were created for work and investment, and this brought more people to cities as workers. However, urbanization leads to LUC in many metropolitan areas around the world, especially in developing countries, and Egypt is no exception. The unprecedented population growth coupled with the informal developmental activities in Egypt has led to urbanization, which lacks infrastructure facilities and caused damage to Egyptian agricultural lands.

The study of land-use has become a very important factor for global change, as LUC has direct impacts on the environment. LUC always requires high attention and priority. In last decades, more attention has been paid to urban sprawl as the impact of human behavior is affecting the urban ecosystems [5]. Urban sprawl is an important aspect of LUC studies. Urban sprawl can be defined as the spread of new development of an urban area to the surrounding land out of the formal planning regulations. LUC caused by urban sprawl requires considerable attention and prioritization, especially in a developing country like Egypt. Urban sprawl is responsible for the disorganized use of land resources and energy, and the large-scale intrusion onto agricultural lands. Over 70% of growth currently takes place outside the formal planning process, and 30% of the urban population in developing countries live in slums or informal settlements [6]. In Egypt, population growth coupled with unplanned development has led to Informal settlements, which responsible for many problems such as poor quality of life, polluted drinking water, noise and air pollution, improper waste disposal, and traffic congestion.

Urban sprawl causes loss of productive agricultural lands, other forms of greenery, loss in surface water bodies, and reduction in ground water aquifers. There has been a lot of debates on how to confine urban sprawl and conserve agricultural land resources [7, 8, and 9]. There is a demand to constantly monitor such urban sprawl and understand the processes for taking effective and corrective measures towards a planned and healthy development of urban areas. In Giza governorate (The western part of greater Cairo region), there is a huge disparity in between national and international institutions and even amongst the different experts in estimating the total amount of land that was lost in the previous 50 years [10]. Agricultural land loss between 1965-1972 at the national level was estimated to be 50 thousand Acres yearly due to urbanization [11], other scholars estimated the yearly loss of agricultural land was between 20-25 thousand Acres [12], and third group of scholars estimated the amount of land lost to be 44 thousand Acres yearly [13]. between 1973-1983, agricultural land loss increased to 60-70 thousand Acres Yearly. National ministry of agriculture estimated the agricultural land loss during the period 1984-2000, of not exceeding 25 thousand Acres yearly. Adding these different views together will sum up the Egyptian loss of agricultural land to be equivalent to 1.3 million Acres between 1965-2000 in Egypt.

Planning is a widely established approach for managing resource allocation and decision making. It includes the use of collective intelligence and knowledge of future requirements and the need to improve the environment in which people live, work, and spend their leisure time. Local authority requirements become essential to provide more efficient and specific direction for better planning. Therefore, this emphasizes the need for adequate information for planning and developmental activities. In recent times, research on urban sprawl has become a very important factor for the elucidation of global environmental change as it has direct impacts on the local environment and the economy.

Developing countries, like Egypt, have developed planning policies to get over problems resulting from urban sprawl, and try to cope with the new demands created by the increasing concentration of people in cities and efficient land-use planning enforcement. These planning policies include forecasting future changes or trends of developments through urban simulation modeling [5]. The measurement and monitoring of these LUC are essential to understanding land cover dynamics over different spatial and temporal time scales for effective land management.

The conventional mapping techniques which were vastly utilized as planning tools become time-consuming and costly. Mapping from remote sensing (RS) techniques has very much advantage because it is synoptic, repetitive and multi-temporal. RS technique is cost effective and a versatile tool for mapping and monitoring of natural features and as well as manmade features [5]. The availability of spatial data and advanced evaluation techniques offers a significant improvement for analysis, ascertaining, depiction, and modeling of urban dynamics. The combination of spatial data and analytical methods should provide support to city planners, and resource managers in their planning and decision-making [14]. Dynamic spatial urban models provide an enhanced capability for evaluating future development and generating planning scenarios, which also allow exploring of the impacts of different urban planning policy implementations. The spatial technology includes both aerial and satellite-based observations with high resolution and high temporal frequency, which is along with geographic information systems (GIS) offers a platform to produce various options for modeling and planning process and can facilitate the spatial data analysis.

To overcome urban sprawl problems, urban studies tried to search for better urban forms that can help to sustain development and minimize of agricultural land loss. there are four operational criteria for sustainable urban forms were recommended [15]: first, not to convert too much agricultural land at the early stages of development; second, to decide the amount of land consumption based on available land resources and population growth; third, to guide urban development to sites which are less important for food production; and fourth, to maintain compact development patterns.

1.2 research problem

The conversion of agricultural lands to urban land-use has caused various negative impacts on ecosystem structure, function, and dynamics [16, 17]. Persistent LUC processes accompanying with urban sprawl phenomenon are expected to accelerate in the next several decades, which will lead to more worsening conditions of crowding, housing shortages, insufficient infrastructure, and increasing urban climatological and require consistent monitoring of urban regions [18].

The emergence of urban sprawl over agricultural lands is perceived as a disaster, this phenomenon is becoming the common pattern in the GCMR urban development. It is estimated that more than 80% of the buildings in GCMR are informal. The Information and Decision Support Center (IDSC) conducted in 1993 estimated that Giza has 32 informal settlements, part of them has a population of more than 1 million inhabitants [19].

Urban sprawl caused a wide conversion of agricultural land to urban land-use which becomes a serious issue in recent years. A large amount of such land has been unnecessarily lost and the forms of existing urban development cannot help to sustain its further development [10]. Therefore, more and more agricultural lands have been converted into urban areas and human settlements over the past few decades [20, 21]. Understanding the causes and consequences of urban sprawl processes to explore the extent and location of future LUC is very important. LUC is often seen as a function of socio-economic and biophysical factors that are referred to as the urban sprawl driving factors [22]. The driving factors that influence the magnitude and extent of LUC are often related to the functioning of local and national markets, policy, and demographic conditions.

However, monitoring of LUC is needed to understand and predict the dynamic process of land-use patterns. This was traditionally limited due to labor-intensive fieldwork that is often unable to reveal the spatial pattern of LUC and environmental consequences that occurred in a given time period. Significant technological advancement in data acquisition and analysis techniques in recent years has made it easier [23, 24, and 25]. RS data coupled with fieldwork information and GIS have been recognized as effective tools in quantitatively measuring spatial patterns and their changes over relatively large geographic scales [23, 26-30]. RS images from airborne and satellite sensors provide a large amount of cost-effective, multi-spectral, and multi-temporal data to monitor LUC processes [14, 18]. GIS technology provides a flexible tool with which to store, analyze, and model the digital data for the detection of change [25, 29].

In developing countries, the lack of readily available and directly accessible information hinders the establishment of management mechanisms and activities crucial to the management of urban sprawl. In urban sprawl studies, there appears to be an imbalance between efforts devoted to either development plans or urban environment. It is very important to control and manage anticipated urban growth otherwise, it leads to urban sprawl. Moreover, it is essential to monitor and assess the proposed plan and policy for urban development with the time. Most of the urban sprawl studies have focused on the physical mapping of urban sprawl and prediction aspects of the connectivity without giving adequate attention to the gap between planning and implementation of the plan and assess possible imbalance. Furthermore, In Giza context, using spatial technology tools is still limited to record the conversion of the non-built-up area to built-up area.

The Change detection techniques for studying urban sprawl is a good approach, however, it has drawbacks such as it only records a static temporal and spatial change between defined time intervals. There is no way to simulate the urban sprawl process by using the Change detection techniques, in order to pin points on key factors that lead to such sprawl ; modelling future urban sprawl under present conditions cannot be achieved ; and There is no way to test the effect of different planning actions on future urban sprawl over agricultural land. Therefore, there is a lack inaccurate methodological approaches for dealing with the dynamics of urban sprawl and future prediction of such sprawl, which are the main concerns addressed throughout this research. Another issue addressed in this research is the problem of the assessment planning policies, through modeling the effect (loss or maintenance of agricultural areas) of such policies on the urban sprawl rate and pattern of change, in the form of "What-If" analysis that will help test different planning actions that can be made to hinder the urban sprawl.

All in all, mapping urban sprawl provides a picture could help to identify the environmental and natural resources threatened, and suggests the likely future directions and patterns of sprawling land-use, Moreover understanding the nature of this phenomenon. A methodological approach is thus needed to help to assess the urban sprawl in Egyptian cities, trying to forecast future urban sprawl, and assessing planning actions' effect of the increase/hinder of urban sprawl at the expense of agricultural areas. This will provide basic infrastructure for the complex urban environment, and up-to-date information related to the dynamic processes. Thus having an urban sprawl model that's calibrated for the Egyptian context is of a great importance to overcome the lack of accurate assessment of the effect of urban sprawl on Egypt agricultural lands. This calibrated urban sprawl model will help in the identification of patterns of sprawl and analyzes of spatial and temporal changes that occur in Egypt cities based on highly updated data acquired from RS. The calibrated model will also help in trying to forecast the future spreading of urban sprawl based on historical data.

1.2.1 Scientific relevance

The urban sprawl phenomenon has attracted considerable attention in the urban context. Previous studies of urban sprawl phenomenon have focused on quantifying and measuring urban sprawl [5, 14, 31, and 32], analyzing the patterns of urban sprawl [33-35], monitoring urban sprawl [37-40], managing urban sprawl [41-44] and modelling urban sprawl [45-50]. These studies have provided valuable insight into the urban sprawl phenomenon and its consequences. Although the significance of these studies, there are still important limitations.

First, the complexity of the urban sprawl phenomenon is less researched in an urban context. Urban sprawl is a complicated process that involves LUC of different socio-economic and physical components at different scales [48]. Dynamic and mutual interactions exist in sprawl process concurrently with different driving forces. The very important issue is the way that cities are spatially and temporally growing, the urban sprawl and the consequential urban forms, which contribute significantly to LUC problems. Understanding this complex mutual interaction enriches our insights relating to the rapid urban sprawl consequences on land-use and bridges the knowledge gap underlying the urban sprawl phenomenon complexity. This, in turn, will provide urban planners and policy makers with new theoretical concepts.

Second, RS and GIS techniques have been widely applied in urban sprawl studies. These techniques have provided significant insight into analyzing and monitoring urban sprawl [51, 52]. Various methods have been applied for mapping and quantifying urban sprawl using these techniques [34, 53- 56]. Nevertheless, there is a general lack of research on the development of methods and indicators using these techniques to quantify the complex of urban sprawl phenomenon, its drivers, and their interactions. In fact, there is a considerable gap in the literature regarding the development of indicators to quantify and study urban sprawl [57, 58]. Alongside, there is a lack of research on the development of indicators to quantify and analyze the spatial-temporal relationship between urban sprawl drivers and their interactions. Therefore, the development of new indicators will bridge the knowledge gap in urban sprawl process research and will provide a significant understanding of the complex interactions of the urban sprawl phenomenon [14, 59, and 60].

Third, the study of urban sprawl driving forces requires sophisticated methods. Recent advances in spatial analysis and statistics methods in combination with RS and GIS techniques provide a significant opportunity for in-depth study of this complex process nature. Newer methods of spatial analysis and statistics have proven relevant and useful in an urban context [61]. Analysis of the spatial association and dependency has gained attention in urban analyzes

[62-64]. However, only a few studies have been conducted using spatial association analysis and dependency analysis in urban studies. There is a lack of research using these methods for exploring urban sprawl drivers and their interactions. We can apply these methods to understand the complex urban sprawl phenomenon and its interactions. This would help in strengthen our understanding of the urban sprawl phenomenon in the context of GCMR and related causing factors and to extend the knowledge of urban analysis.

Fourth, although urban modeling approaches have offered an innovative insight into the deeper understanding of the urban sprawl phenomenon, most of the existing urban sprawl models ignore the complex socio-economic, physical components and mutual interactions between the influential drivers. These models focus on the physical interactions of urban systems and model LUC based on the spatial influences of different factors. The socio-economic is considered one of the main factors of LUC in most of the existing models [46, 65- 68]. The socio-economic influences LUC through the level of accessibility it provides, and it is incorporated in the current urban sprawl models in a temporal-static way. However, the mutual effects of LUC and socio-economic are not considered in most of these models. In essence, there is a lack of integrated dynamic models of urban sprawl models relating to the complex spatial and temporal mutual socio-economic interaction. Therefore, modelling the complex urban sprawl and socio-economic interaction facilitates the investigation of the complex interaction between the urban sprawl phenomenon and urban systems, the estimation of future impacts on LUC and socio-economic, the development of existing plans and policies, and the consideration of alternative planning and policy interventions to minimize the impact of the negative aspects of urban sprawl.

1.2.2 Social relevance

Traditional urban planning approaches cannot accommodate the negative consequences of urban sprawl, to eliminate these negative consequences and to provide a better planning practice, and understanding of the mutual interaction of urban sprawl and its drivers in the case of fast-growing regions can contribute to urban planning approaches in different aspects.

First, the negative consequences of urban sprawl on land-use attract considerable attention to the urban planning and management practices in both developed and developing countries. A thorough analysis of the mutual interaction of urban sprawl and its drivers for individual case studies of a fast growing regions (Giza, in this research) can be helpful in sharing experiences and learned lessons.

Second, many cities in developing countries lack sophisticated methods for analyzing the complexity of urban sprawl and its drivers. This research helps to develop easy-to-use measures, indicators and methods for quantification and analysis of the spatial-temporal relationship between urban sprawl and its drivers to support the analysis and the understanding of urban sprawl complexity and urban dynamics in these countries.

Third, the current urban planning practice of most developing urban regions lacks methods and tools for land-use-physical and socio-Economic factors analysis that can incorporate urban sprawl. Dynamic modeling of the mutual interactions in rapidly growing urban regions will provide a new planning tool for understanding this complex dynamic interaction. Knowledge about the process of this interaction helps to predict future negative consequences, which helps to mitigate the negative aspects of rapid urban sprawl through policy interventions analysis.

Fourth, most of the current planning practice in rapidly growing urban regions focus on a separate vision relating to specific land-use issues and lacks the decision support tools of policy intervention analysis, scenario-building, and prediction in early land-use planning stages. Moreover, integrated land-use planning processes and agricultural lands protection policy formulation is still absent in current planning practices. Dynamic modeling of the interaction between urban sprawl and their drivers can provide a step forward for decision-making support and appropriate policy intervention analyzes. Urban planners and policy makers usually require a simple measure to understand land-use policy implications. A dynamic integrated land-use model helps simulate the future consequences of different integrated land-use policy interventions. This can provide a new integrated land-use planning approach to face urban sprawl over agricultural lands and related driver's challenges at early planning stages.

1.3 Research objectives

The main objective of this research is to analyze and understand the spatial-temporal relationship between urban sprawl and their causing socioeconomic and physical driving forces and find their potential impacts on urban attributes and agricultural lands in 2035 in order to support urban in Giza.

The specific objectives of this research are:

1. To identify the effects of changes in accumulated governmental housing policies to meet the rapid urban sprawl rates of the informal low-class housing.
2. To develop spatial indices to quantify and analyze the spatial-temporal urban sprawl patterns in Giza governorate.
3. To explore the socio-economic and physical driving forces and their influences on urban sprawl.
4. To assess the consequences of different policy interventions on future urban sprawl patterns and potential risks on agricultural lands.

1.4 Study area

Giza governorate was examined in this research to analyze and understand the nature of urban sprawl and their influences. Egypt has experienced a high urban sprawl rates over the last five decades. The major governorates in Egypt, including Giza, have experienced rapid urban sprawl [12]. Giza governorate has witnessed a remarkably rapid urban sprawl rate during the past three decades. Giza has witnessed a dramatic increase in population primarily due to out-migration from villages and from suburbs to the capital by individuals in search of jobs and better living. The strength of the economy and the growth of the population are increasingly straining the housing sectors and other related services in addition to shrinking of agricultural lands. Giza experiences various haphazard and interrelated urban land-use and agricultural land loss issues. The challenges of accelerated urban sprawl, population growth of informal areas and agricultural land loss are currently the main issues in Giza, and its local government faces many challenges in managing its urban sprawl and protecting agricultural lands.

1.5 Thesis outline

This thesis consists of eight chapters. In addition to the introduction (1) and synthesis (8) chapters, this thesis includes six core chapters (2-7) that address the research objectives. These five chapters have been published as peer-reviewed papers in ISI journals or international conferences. Figure 1.1 shows the coherence of the thesis chapters. The following is a brief summary of each chapter:

Chapter 1: provides a general introduction to the thesis. First, the rationale for this research topic and its scientific and social relevance is introduced. Then, the research objectives, the study area and an outline of the thesis are introduced.

Chapter 2: discusses the nature of the housing policies changes and their effects on the housing issue in Giza. Primary data were derived through questionnaire survey and secondary data from national censuses. The analysis results reveal that the change in the general state policies failed to end the phenomenon of the urban sprawl of low-housing class uses in Giza, however, the success in attracting more investments for public housing of low-income residents.

Chapter 3: Focusing on Giza governorate as a case study, this chapter describes the nature of the urban sprawl phenomenon in GCRM on current literature. Then, it quantifies and analyzes the spatial-temporal urban sprawl using RS and GIS approaches in the period from 2004 to 2013. The results reveal the highly quick growing of urban sprawl areas in Giza governorate with low efficacy and dysfunctional spatial disposition urban characteristics.

Chapter 4: First, the socio-economic driving forces of urban sprawl and their relative influences using Analytic Hierarchy Process (AHP) method are presented. The AHP model is using data identified by field survey and interviews with related local experts. AHP resulted in a weight matrix for socio-economic drivers in Giza.

Chapter 5: By using logistic regression (LR), the physical forces and their influences are shown. 2004-2013 Landsat and vector data acquired from GOPP was applied in the LR model. LR resulted in a probability map for urbanization in Giza governorate 2004-2013 based on the applied physical forces.

Chapter 6: Considering The whole western part of GCMR as case study, Three urban development scenarios, historical growth trend (HGT), compact growth (CG) and growth as planned officially (GPO), were introduced to better understand the relationship between urban dynamics and their risks on Agricultural lands. The future urban sprawl patterns and their risks of submitted urban scenarios in 2035 were modeled using an integrated model of Markov chain (MC), LR, and cellular automata (CA).The findings proved that no threats on total area of agriculture lands on the regional scale study due to the reclamation activities added a new agricultural lands areas more than the area of loss until 2035. However, on focusing on the local scale study inside the administrative borders of north, middle, and south sectors there are high rates of agricultural land loss due emerging urbanization particularly in middle sector.

Chapter 7: Focusing on the middle sector of the western part of GCMR as case study, By using SLEUTH model and required data, included Slope, Land-use, Exclusion, Urban sprawl, Transportation and Hillshade, the three urban scenarios effects were investigated. The results of SLEUTH method reveal highly matching in the predicted urban sprawl patterns and their risks on Agricultural lands in 2035 in middle sector with the findings from the integrated model of Markov chain (MC), LR, and cellular automata (CA).

Chapter 8: provides a synthesis of the obtained results and the conclusions of chapters 2-5. A reflection on the main contributions of these chapters is provided. Then, recommendations are given for further research.

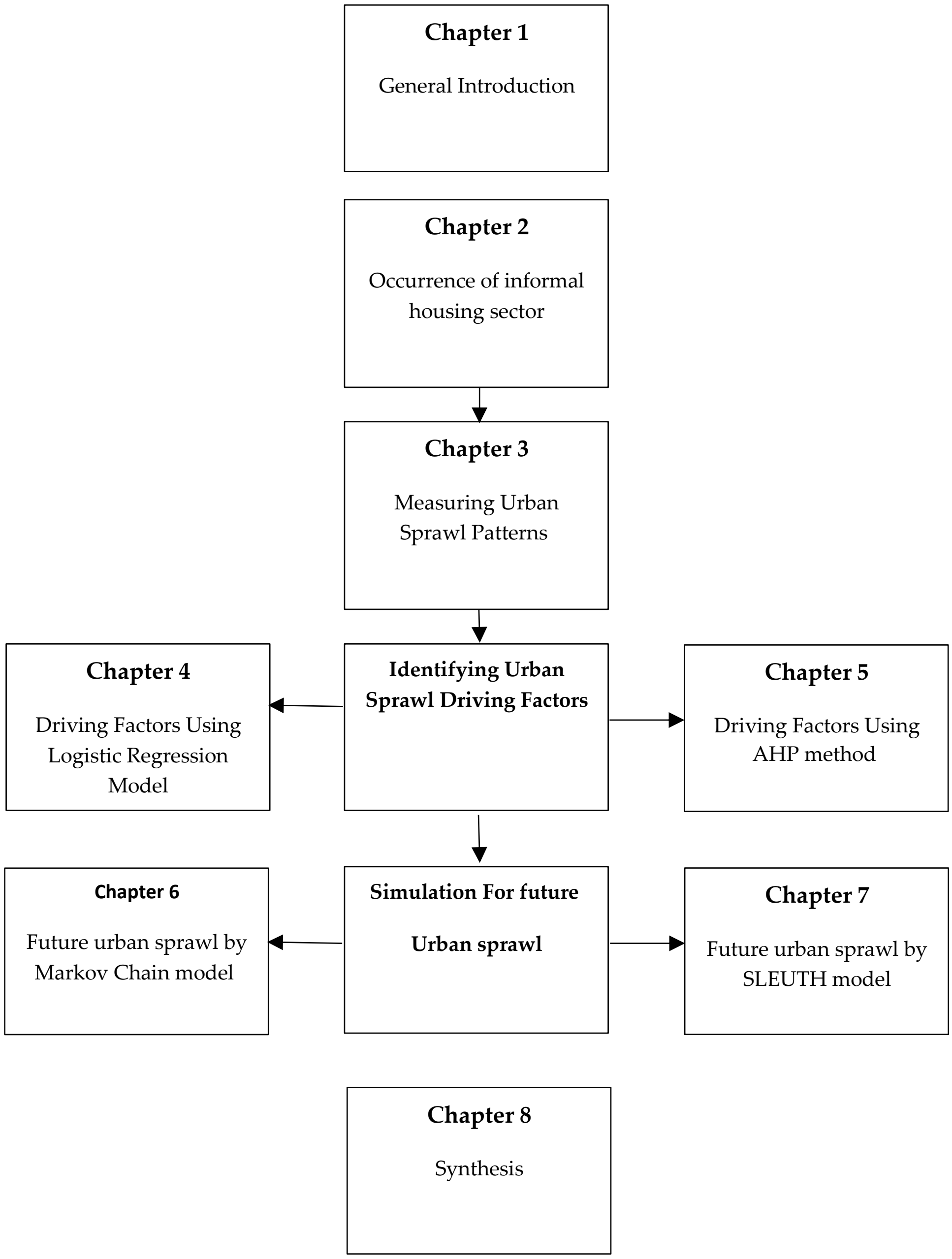


Figure 1.1 Coherence of thesis chapters and their relationship

1.6 Review of previous studies

1.6.1 Informal housing phenomenon as a physical act of urban sprawl dynamics

The chronological process of transforming agricultural land to residential uses is inverted for informal settlements compared to formal settlements. Whereas informal procedures the normal course of events in general starts with the acquisition of the title of ownership, followed by the provision of services like roads, water, and electricity afterward buildings are constructed and finally the inhabitants move in. The informal procedure completely inverts the order of these steps as it starts with the invasion of the plots by the informal settlers. The plots are not equipped with any services or urban fabric and invaders construct simple huts or directly start to work on buildings. This situation might last for decades before the provision with infrastructure and utility providers decide to supply services or the residents find alternative ways to supply themselves. However, the attainment of ownership titles might mark the end of a long process in the informal housing sector [69].

Informal housing areas comprise a broad range of informal activities. The emergence of informality can have manifold reasons. For example, informality arises if formal activities are too expensive for the poor to be conducted within the legal framework. Moreover, restrictions on access to the formal markets, which defined by the legal framework or an insufficient fulfillment of market demands such as delivery of designated housing land that can entail informality. Informality is reinforced where the state is not able to accomplish the applicable law [69]. The failure of the state can be caused by insufficient financial and personnel public capacities, an inadequate legal framework or administrative system, the behavior of public services. Which result in an insufficient capability to respond to public demands for public housing or supply of serviced plots. Those demands become subject to the informal market in the form of informal enterprises, informal transport services, and informal land markets to name just a few. The growth of informal areas reflects the gap between demand for land and its provision by the formal sector, unable to provide housing for the poor. It can thus be viewed as a response on the part of poor households excluded from urban housing markets and who cannot afford to pay formal market rents to reside. These processes are fueled by rural immigrants and poor urban population growth [70].

As many urban residents are poor they cannot afford to participate in the formal housing market. Therefore, most of the population growth are absorbed into informal housing areas [71]. But due to its capacity, the formal sector cannot keep pace with the demand. Informal settlements have been the dominant sector in housing supply in the last decades in most African metropolitan regions. In 2005, 922 million people lived in the Africa, 36% of them in urban areas. 2. 51% of the urban areas dwellers lived in informal areas. In GCMR, 60% of the inhabitants lived in informal housing areas [71]. Informal housing emerges due to some forces such as income inequality, lack of economic growth and immigration. This leads to more urban poverty, and a lack of affordable housing which leads to more of informal housing areas formation.

Related to informal housing areas, informal economy that includes informal enterprises which operate the informal sector of market economies. Older theories understood informal economic activities as a phenomenon which just occurred as a solution for labor force who migrates from the rural areas to urban areas, and cannot find a job in the formal economic sector. However, studies in the 1970s showed that this phenomenon was no interim solution for migrants but an own type of employment in developing countries [71]. The majority of informal housing residents in developing countries earn their living from informal sector activities located either within or outside informal housing areas [6].

The informal economy consists of many different activities such as home-based work, street vendors, entrepreneurs, self-employed, and casual workers [72]. Most of the informal enterprises consist of very small survivalist activities operated by the urban poor of the community which allows their owners to achieve a decent standard of living [73]. An estimated 60% of those earning a living in the informal economy are self-employed, and African countries this figure rises to over 90% [74]. In the majority of African mega-cities, the formal economy participates only with a small proportion of the total urban employment, usually with a rate of 5-10% [75]. Reliable data and comparable definitions are lackings, which makes it hard to come up with regional estimates. It is assumed that around 70% of activities in the urban economies of Africa are informal [76]. In the 1990s, ILO estimated that the informal economy would generate about 93% of all additional jobs in urban Africa [77].

In GCMR, Informal housing areas which first appeared in the 1960s falls into two categories: informal housing areas located on former agricultural land, and informal housing areas on former State land which are mostly desert. Over the last 50 years, most of the informal areas were developed on agricultural land. This trend will continue as long as alternatives are not offered to informal land and housing markets [78]. The erosion of agricultural land since 1980 is estimated at about 1 million Acres. This corresponds to a yearly loss of 0, 6% of Egypt's total agricultural land. Between 1980 and 2025 nearly half of Egypt's agricultural land will be converted to informal housing areas [78]. The lack of physical planning in informal housing areas is a product of their extra-legality [79]. This results in extremely high population densities and high pollution rates. Nevertheless, the quality of construction is often good. A study of satellite images revealed that the surface area covered by informal settlements in GCMR between 1991 and 1998 increased by 3.4 % annually. The population residing in informal areas grew by 3.2 % annually. At the same time, the population growth in GCMR's formal settlements amounted to 0.8 % annually. [21].

1.6.2 Spatial Metrics for Analysis of Urban sprawl Dynamics

Quantifying land-use patterns, analyzing the changes over time, and identifying the causes of changes are essential for monitoring the spatial process of urban sprawl and their consequences in Giza. There is a lack of studies focused on LUC in Egypt due to the lack of spatially consistent databases over time. Therefore, an integration of fieldwork, RS, GIS, LR, and AHP techniques is proposed to interpret the patterns of LUC over time, and the driving factors of these changes. This study focuses on the spatial process of urban sprawl rather than the socioeconomic process. The spatial process of urban sprawl brings changes in the spatial patterns of land-use over 2004-2013. Therefore, the study heavily relied on LUC to synthesize the spatial process of urban sprawl in Giza.

Land-use maps derived from RS data explicitly exhibited the dynamics of urban sprawl phenomenon. Yet, some underlying patterns and characteristics could not be visualized clearly. spatial indices, quantified and represented the spatial-temporal patterns of urban sprawl, improved understanding of the morphology of heterogeneous urban areas, provided a linkage to structure, pattern, processes and functionality in urban ecological studies, and bridged social and ecological dynamics of urban social-ecological systems as well not only in Egypt, but also for similar case studies in developing countries [78, 80-84].

Many studies have focused on the development of different indices portraying different aspects of LUC, and numerous indices emerged at a time since the spatial indices were initiated in the late 1980s [85]. However, some theoretical issues of spatial indices were still under investigation. Previous attempts at the systematical examination of how the commonly used spatial indices respond to changing the direction of analysis. The results demonstrated that 19 spatial indices fell into 3 general categories with different variation rules [86,87].The explore of scaling relations for LUC patterns exist when they are measured over a range of scales. the results highlighted the need for multi-scale analysis to characterize and monitor LUC heterogeneity [88]. LUC response to urbanization can be better revealed within larger spatial units such as metropolitan areas [89]. The study of effects of RS resolution on LUC fragmentation found that fragmentation indices were sensitive to a varied spatial resolution that indicated to fine resolution data might be optimal for urban fragmentation analysis as well [90]. The study of effects of thematic resolution on LUC pattern analysis showed that changing resolution may significantly affect spatial indices with consistent general patterns but is likely to be dependent on specific LUC patterns and classification criteria in detailed patterns [91].

Previous studies were performed to clarify how mapped data from RS can affect spatial indices which can help improve the reliability of LUC pattern analysis [92]. These studies affirmed that specific spatial index, scale, classification schemes, and other related issues should be taken into consideration when a specific LUC analysis task is executed. The most frequently used indices in the existing case studies were: Percentage of LUC, Patch Density, Edge Density, Largest Patch Index, Mean Patch Size, LUC Shape Index, and Area Weighted Mean Patch Fractal Dimension. Shannon's diversity index, Shannon's evenness index, and the contagion index are usually applied too. With the further understanding of theoretical-related issues, spatial indices have been improved and widely used for characterizing various LUC patterns in the past few decades, while only recently have they been applied to the study of urban morphology [14, 80, 81, 93-97]. In this paper, the term "Spatial Indices" is accepted to refer to the application of urban sprawl metrics outside urban ecology and across different kinds of environments [98].

the application of spatial metrics for LUC dynamics, some studies focused on only temporal characteristics [89], and some concentrated on only spatial properties [81,99] while others were concerned with both sides[14,96, 97, 100,101]. For temporal analysis, the time span is usually one decade or several decades. The conventional data source is time series optical images. For example, historical aerial photographs, Landsat MSS/TM/ETM+ images, SPOT, and IKONOS images. Most existing analyzes were based on thematic maps derived from optical images and very few studies paid attention to the analysis of simulation results. For LUC spatial pattern analysis, the key point is how to choose the sample regions that reveal the significant spatial difference effectively. Previous studies initiated to make a combined approach of gradient analysis with spatial indices. Thereafter transects analysis became a popular and effective method to demonstrate spatial patterns of urban LUC [81, 99], and to execute this analysis across three concentric from the city centers [97].

In addition, some researchers calculated the spatial indices based on administrative districts [100] or different homogeneous urban patches [96], For example, in USA (Santa Barbara, California; Arizona; Kansas; Madison, and Wisconsin), China (Hangzhou; Daqing; and Shanghai), and in a few cases, Canada (Sooke, Vancouver, and Toronto) and Stockholm, Sweden. LUC research in Europe has historically emphasized human–environmental interactions and the empirical methods were generally accepted, which partly accounted for the lower popularity of spatial indices in Europe while quantitative approaches were the mainstream methods in American LUC research, and spatial pattern analysis and modeling [88].

RS has long been used to map urban sprawl and urban morphology, and implies the mapping of the form, land-use, and density of urban areas, each having an associated shape, configuration, structure, pattern, and organization of land-use [18,102-104]. Sometimes simply mapping an urban or non-urban dichotomy is important; sometimes detailed morphologic mapping is needed, where the positions of buildings and roads or the extraction of the three-dimensional topographical aspects of urban areas are needed.

Recent advances in RS and the increasing availability of high-resolution earth observation satellite data provide great potential for acquiring detailed spatial information to monitor a number of environmental problems in urban regions at desirable scales [18, 30,103]. Transitions in architecture and building density, vegetation, and intensive socioeconomic activities at the block level often responsible for LUC, which become more heterogeneously [105]. Therefore, the urban environment represents one of the most challenging areas for RS analysis due to the high spatial and spectral diversity of surface materials [96,106,107]. In recent years, a series of earth observation satellites has provided abundant data at high resolutions (0.6-2.5 m; QuickBird, IKONOS, OrbitView, SPOT, and ALOS) to moderate resolutions (15-30 m; ASTER, IRS, SPOT, and LANDSAT) for urban area mapping. RS data from these satellites have the specific potential for detailed and accurate mapping of urban areas at different scales. The high-resolution imagery provides data for monitoring urban infrastructures, whereas moderate resolution imagery can provide synoptic measures of urban sprawl, surface temperature. A wide range of urban RS applications from both sensors is currently available [18, 52,106-109]. These include quantifying urban sprawl dynamics, population estimation, life quality improvement, urban infrastructure characterization, monitoring land surface temperature, air quality, vegetation, and topographic mapping.

However, computer-assisted image classification is still unable to produce land-use maps and statistics with high enough accuracy [107,110]. Image analysis techniques are evolving rapidly, but many operational and applied RS analyzes still require extracting discrete thematic land surface information from satellite imagery using classification-based techniques [111]. Several image classification techniques, from automated to manual digitization, can be found in the literature [110-113]. However, these studies have spanned a broad range of land-surface types and sensors. Different image classification methods use data from different satellite sensors to determine how the organization of information inherent to the classification scheme influences classification accuracy and the representation of the earth surface in thematic meaning. Several studies argued that the heterogeneity of LUC require classification techniques that combine more than one classification procedure to improve RS-based mapping accuracies [102,110,114].

1.6.3 Socioeconomic, and physical driving forces of urban sprawl Dynamics

The LUC process is a nonlinear dynamic change that includes many related ecologic, geographic, economic, and social factors and interrelations [115]. The spatial configuration of land-use is an important determinant of many ecological and socioeconomic processes [116-118]. LUC is usually driven by a variety of forces which relate differently to one another in different spatial and temporal settings.

In practice, many processes that influence LUC interact and lead to complex patterns, depending on the local cultural, socioeconomic, and biophysical context at different spatial scales [116]. At a wider perspective, LUC is also an important factor in the climate change cycle, and the two are interdependent; changes in land-use may affect the climate while climatic change will also influence future land-use patterns [119,120]. Therefore, LUC research has received much attention during the past decade because of the pivotal role of LUC in many urgent issues like global climatic change, food security, soil degradation, and biodiversity deterioration [116]. LUC research involves many disciplines because it operates at the interface of the natural and human sciences [116]. LUC is the result of the complex interaction of behavioral and structural factors associated with demand, technological capacity, social relations, and the nature of the environment. A theory of land-use change, therefore, needs to conceptualize the relation between the driving forces and land-use change, relations among the driving forces, and human behavior and organization.

From a geographical discipline, LUC studies have been carried out mainly at the national and sub-national level, using available geographic information from maps, census data, and RS. These data have been used to construct driving factors of LUC that are used to explain the locations of these changes [121-123]. These studies often lack explicitness about processes and human behavior. The drivers used are proxies for the processes that determine land-use change. The identified relations between LUC and the projected driving factors are valid at the regional level and do not straightforwardly translate into the determinants of LUC at small scales. The strength of this geographical approach is its spatial explicitness, which helps to explain land-use patterns and can be directly used in geographical modeling approaches

[123,124]. However, this approach contrasts with the approach of the social sciences, which generally conduct micro-level studies aimed at understanding people-environment relations [109,125]. Socioeconomic studies often focus on small scales levels to gain insight into the factors that influence land-use decisions. These studies provide information about decision-making processes and human behavior. However, they do not incorporate a spatial component.

Basically, we can consider two main categories for LUC drivers: biophysical and socioeconomic. The biophysical drivers include characteristics and processes of the natural environment such as weather and climate variations, landforms, topography, geomorphic processes, volcanic eruptions, soil types and processes, drainage patterns, and the availability of natural resources [126]. The socioeconomic drivers comprise demographic, social, economic, political, and institutional factors and processes such as population and its change, industrial structure and its change, technology and technological change, families, the market, various public sector bodies and related policies and regulations, values, community organization and norms, and property regimes [127]. It should be noted that the biophysical drivers usually do not cause LUC directly. They mostly cause land cover changes that, in turn, may influence the land-use decisions of landowners/managers [118].

An improved understanding of LUC is considered to be a requirement for the global assessment of urbanization processes in agriculture environment with reference to their various functions, including biodiversity, aesthetics and cultural heritage, and production levels. Thus, this understanding will contribute to the development of management strategies and policies to restructure or prevent further decline in the environmental value of mountain agriculture. Given the complexity of human/nature systems and the scale dependency of LUC drivers, the need for approaches that integrate socioeconomic and biophysical drivers are now widely recognized [116,126,128]. At present, case studies are important for gaining an understanding of the complex relationships between the social and natural systems that drive LUC and land resource change [117,129-134].

A range of methods, from econometric to probabilistic, is used to understand the LUC drivers in many urban regions which are an important aspect of modeling future land-use scenarios. However, this research focused on exploring the driving factors of LUC in Giza with the people participatory approach. The participation of local experts in the decision-making process to understand the processes of their surrounding environment is very important. Modeling the driving factors, including local experts' perceptions, and driving a thematic meaning of the LUC process has been a challenging topic due to its complexity nature as a range of factors plays different roles at different scales in a particular place, and most of the driving factors are interlinked with each other. The driving factors should be dealt with as multi-criterion problems, as there are different levels of relations between the factors, therefore, more than one criterion should be considered while measuring the weight of the driving factors and when making decisions.

To solve the multi-criterion problems analytically, the AHP method was introduced, which has a sound mathematical foundation in late of the 1970s [135]. Since it has been widely used in several socioeconomic and engineering applications [25,136-138]. The AHP method is a general theory of measurement that derives ratio scales from both discrete and continuous paired comparisons in multilevel hierarchic structures. These comparisons may be taken from actual measurements or from a fundamental scale that reflects the relative strength [135]. It has been applied to a variety of prediction and multi-criteria decision problems. AHP works in a nonlinear framework, carrying out both deductive and inductive thinking, taking several factors into consideration simultaneously. Also, AHP allows for dependency and feedback and making numerical tradeoffs arrive at a synthesis [139]. Furthermore, the AHP provides a multi-criteria decision support method that land-use hierarchical structures to represent a problem, then develop priorities for alternatives based on the judgment of the respondents [25,138].

1.6.4 Spatial-Temporal Modeling for Simulation of Urban Scenarios

Pattern description, change detection, spatial statistics, and regression analysis are commonly used in traditional urban development researchers. With the developments of RS, GIS, and large-scale computing and visualization techniques, urban simulation models have been developed to understand urban development dynamics and anticipate urban planning activities [5,140]. Urban simulation models can be used to trace urban trajectories in the past and predict urban development scenarios under different "what if" conditions in the future. The outcomes of these models can assist policymakers in evaluating alternative development schemes and making urban planning policy recommendations [14,141].

LUC has been considered as a complex dynamic process that links natural and human systems. It has direct impacts on soil, water, and the atmosphere, and is thus directly related to many environmental issues of global importance [142,143]. The large-scale deforestations and subsequent changes of agricultural land in the tropics are examples of such LUC [122,130,144,145]. In LUC studies, some researchers have focused on urbanization from the perspective of either economic geography [146] or from a more technology-driven perspective that focuses on the interaction of land-use through CA models [14, 52, 66,147-151].

LUC models can be summarized into four categories, that is, empirical statistical models, stochastic models, optimization models, and process-based dynamic simulation models [152]. Actually, the dynamic simulation models classification systems were usually hybrid models: different methods were coupled in an integrative model. When simulating urban sprawl, many researchers merely focused on baseline projection [14,153] and urban sprawl scenarios were relatively understudied. Even when scenarios were considered, different scenarios were designed according to specific development strategies in specific cities. For instance, The ecological modeling consequences of land-use policies scenarios in New Jersey [154], and by using high or low population density as two different development options in the simulation of Hongkong [155]. Also, simulation of urban sprawl in Beijing using different urban land demand scenarios of water shortage [156].

So far, there have been no reported scenario simulations of future Giza governorate growth. As Giza is experiencing the transition from Agricultural-manufacturing-center to the service center, which development policy adopts should lead to significantly different urban future with different environmental consequences. Thus, it is desirable to design and develop suitable scenarios to simulate the growth of Giza to evaluate the real effects and ultimately support decision-making. In addition, the rare previous studies only focused on urban/non-urban simulation [20-21]. Our simulations included seven urban land-use classes, which permit further analysis using spatial indices.

CA, is one of the most frequently urban simulation models, which used by many researchers [14, 48, 140,153,157,162-165]. CA was first introduced by Von Neumann as mathematical representations of complex systems which consist of a grid or lattice of cells where each cell is in one of a number of finite states. The state of a cell depends on a set of transitional rules and the state of neighboring cells. The time component progresses in discrete steps and the cells update their state synchronously after the transition rules are applied. CA has been successfully used to simulate LUC in many regions worldwide, For example, Beijing [156], Shanghai [48], Wuhan [166] and Pearl River Delta [158] in China; Amsterdam, Groningen, Utrecht and Den Bosch in the Netherlands [163]; Comet-Dan watershed, Central Brittany, France [167]; Sintra-Cascais of Portugal [140]; Calgary, Alberta, Canada [168]; Savannah, Georgia, USA [162]; Santa Barbara, California, USA [14]; San Francisco Bay region in California and the Washington/Baltimore corridor, USA [153]; New York [164]. Moreover, CA model has also been successfully used to study a variety of spatial phenomena including population dynamics [169], plant competition [170] , epidemic propagation and vaccination [171], habitat fragmentation [172], cultural LUC reconstruction at long run [173], LUC changes [174], forest insect propagation [175], forest dynamic [176], forest fire behavior [177,178].

Some researchers integrated CA with economic models [179], ecological model [180], or regional development model [148,165,181]. While others loose-coupled the "bottom-up" CA-based model and the "top-down" system dynamics based model [156]. Some studies combined spatial metrics and CA model [14,163] while others downscaled climate change scenarios in LUC- CA model [164]. Some extended CA model based on a relational database to overcome the restrictions of standard CA only in adjacency of neighborhood [182] while others incorporated density gradient [159] and population distribution [183] as a restriction of CA model in the simulation of urban development. Some took dynamic spatial and temporal constraints into consideration [184] while others associated MC analysis and CA in view of the advantage of the accurate transition probabilities of MC analysis and spatial character of CA [140,168]. On the other hand, for the aims of better simulation of LUC. The most critical issue is how to capture the richness of LUC behaviors in the simplifying mechanisms of CA [165]. at the same time, equal attention should be paid to better-defined neighborhood rules [163,185]. Various researchers built up their own transition rules using different methods. For examples, identifying suitability map sets by future conceptual urban structure [168]. Transition rules and multi-criteria evaluation (MCE) were integrated with CA model to simulate LUC in the rural-urban fringe of metropolis [165]. However, for simulating urban sprawl by CA model, the most meaningful work is how to represent the complexity of sprawl that dramatically influenced by both human and natural factors at different scales.

To understand the stochastic nature and the stability of land-use, MC model is very useful. MC model is frequently used to simulate LUC change [187,188], analyze land-use types, trends, and dimension of changes [189]. Due to advancement in GIS technology and its interconnectivity with MC model has become more popular [189,190]. The MC model has been used to examine the stochastic nature of LUC and to project the stability of land development for the future. The MC model is one of the models that allow for the study of LUC [187]. The MC model is frequently used to simulate LUC change and analyze land-use types, trends, and dimension of changes, which has gained popularity due to advancements in GIS technology and its interconnectivity with RS. [188-190].

References

[1] UNIS., 2004, United Nations Information Service, http://www.unis.unvienna.org/unis/pressrels/2004/pop899.html.

[2] UN. 1997. World Urbanization Prospects; the 1996 Revision, New York: United Nations.

[3] WRI, UNEP, UNDP and The World Bank., 1998. World Resources Report 1998-99: A Guide to the Global Environment, New York: Oxford University Press.

[4] Kaothien, U., 1995. The Bangkok Metropolitan Region: Policies and Issues in the Seventh Plan, In The mega-urban regions of Southeast Asia, (Eds, McGee, T. G. and Robinson, I. M.), Vancouver: UBC Press, 328-340.

[5] Sudhira, H.S., Ramachandra, T.V., and Jagadish, K.S. (2004). Urban sprawl: metrics, dynamics and modelling using GIS. International Journal of Applied Earth Observation and Geoinformation, 5, 29–39.

[6] UN-HABITAT (United Nations Human Settlement Programme) 2003: The challenge of slums – Global report on human settlements 2003. Earthscan, Nairobi, London.

[7] Bryant,C.R., Russwarm, L.H. and McLellan, A.G., 1982. The city's Countryside:Land and Its Management in the Rural-urban Fringe,Longman Group Ltd, New York,N.Y.

[8] Ewing,R.,1997.Is Los Angles-Style sprawl Desirable? ,Journal of the American Planning Association, 63(1):107-126.

[9] Daniels,T. L., 1997. Where Does Cluster Zoning Fit in Farmland Protection?, Journal of the American Planning Association P.129-137.

[10] El-Hefnawi, A., 2005. Protecting agricultural land from urbanization or Managing the conflict between informal urban growth while meeting the demands of the communities-Lessons learnt from

the Egyptian policy reforms, World Bank - Urban Research Symposium 2005, Institute of Applied Economic Research (IPEA), Brasilia, Brazil.
[11] El-Bakri, B. and Salem, O., 1992. Towards sustainable urban development and managementin Egypt, the UNDP taskforce on strategies for sustainable development in Egypt, UNDP.
[12] Padco et al, 1982. National Urban Policy Study, Ministry of Planning, Egypt.
[13] Zanaty, M. and Badawy, A., 1995. Agricultural land: problems and future, academy library press.
[14] Herold, M., Goldstein, N.C. & Clarke, K.C., 2003. The spatiotemporal form of urban growth: measurement, analysis and modeling. Remote Sensing of Environment, 86(3), 286-302.
[15] Yeh, A. G., 2002. GIS as a tool to manage urban growth in a fast growing region, Centre of Urban Planning and Environmental Management, University of Hong Kong.
[16] Antrop, M., 2000, Background concepts for integrated landscape analysis. Agriculture, Ecosystems and Environment, 77, 17–28.
[17] Mesev, V., 2003, remotely sensed cities: An introduction. In Remotely Sensed Cities, V. Mesev (ed.), New York: Taylor & Francis.
[18] Miller, R. B. and Small, C., 2003, Cities from space: Potential applications of remote sensing in urban environmental research and policy. Environmental Science & Policy, 6, 129-137.
[19] IDSC, 1993. Information and Decision Support Center, Official report about informal settlements in Egypt.
[20] Taher Osman, Takafumi Arima, Prasanna Divigalpitiya, 2015 (b). Measuring urban Sprawl patterns in Greater Metropolitan Cairo Region, Journal of the Indian Society of Remote Sensing, Springer Publications. DOI: 10.1007/s12524-015-0489-6.
[21] Mohamed Mohamed Amin Abd-Allah. (2007). Modelling Urban Dynamics Using Geographic Information Systems, Remote Sensing and Urban Growth Models, PhD thesis, Cairo University, Faculty of Engineering.
[22] Turner, M.G., Costanza, R. and Sklar, F., 1989. Methods to evaluate the performance of spatial simulation models. Ecological Modelling 48, 1–18.
[23] Nelson, R. F., 1983, Detecting forest canopy change due to insect activity using Landsat MSS. Photogrammetric Engineering and Remote Sensing, 49, 1303-1314.
[24] Tang, J., Wang, L. and Zhang, S., 2005, Investigating landscape pattern and its dynamics in Daqing, China. International Journal of Remote Sensing, 26, 2259-2280.
[25] Thapa, R. B. and Murayama, Y., 2008, Spatial structure of land use dynamics in Kathmandu Valley, In The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, J. Chen, J. Jiang and A. Peled, (eds.), ISPRS XXI Congress Proceedings, XXXVII(B8), pp. 11-16, Beijing: Organising Committee of the XXI International Congress for Photogrammetry and Remote Sensing.
[26] Frohn, R. C., 1998, Remote Sensing for Landscape Ecology, New Metric Indicators for Monitoring, Modeling, and Assessment of Ecosystems. Florida: Lewis Publishers.
[27] Petit, C., Scudder, T. and Lambin, E., 2001, quantifying processes of land-cover change by remote sensing: resettlement and rapid land-cover changes in south-eastern Zambia. International Journal of Remote Sensing, 22, 3435-3456.
[28] Longley, P. A., 2002, Geographical information systems: Will developments in urban remote sensing and GIS lead to "better" urban geography? Progress in Human Geography, 26, 231-239.
[29] Murayama, Y., 2004, American influence on Japanese human geography: a focus on the quantitative and GIS revolutions. GeoJournal, 59, 73–76.
[30] Thapa, R. B., Kusanagi, M., Kitazumi, A. and Murayama, Y., 2007a, Sea navigation, challenges and potentials in South East Asia: An assessment of suitable sites for shipping canal in South Thai Isthmus. GeoJournal, 70, 161-172.
[31] Epstein, J., Payne, K., and Kramer, E. (2002). Techniques for mapping suburban sprawl. Photogrammetric Engineering and Remote Sensing, 63 (9), 913–918.
[32] Bhatta, B. (2010). Analysis of urban growth and sprawl from remote sensing data. Heidelberg: Springer-Verlag.
[33] Shenghe, L., Prieler, S., and Xiubin, L. (2002). Spatial patterns of urban land use growth in Beijing. Journal of Geographic Science, 12(3), 266-274.

[34] Schneider, A. and Woodcock, C. E. (2008). Compact, dispersed, fragmented, extensive? A comparison of urban growth in twenty-five global cities using remotely sensed data, pattern metrics and census information. Urban Studies, 45(3), 659-69.
[35] Fan, F., Wang, Y., Qiu, M., and Wang, Z. (2009). Evaluating the temporal and spatial urban expansion patterns of Guangzhou from 1979 to 2003 by remote sensing and GIS methods. International Journal of Geographical Information Science, 23(11), 1371–1388.
[36] Bohnet, I. C. and Pert, P. L. (2010). Patterns, drivers and impacts of urban growth-A study from Cairns, Queensland, Australia from 1952 to 2031. Landscape and Urban Planning, 97(4), 239-248.
[37] Yagoub, M. (2004). Monitoring of urban urowth of a desert city through remote rensing: Al-Ain, UAE, between 1976 and 2000. International Journal of Remote Sensing, 25(6), 1063–1076.
[38] Henriquez, C., G. Azócar, and Romero, H. (2006). Monitoring and modeling the urban growth of two mid-sized Chilean cities. Habitat International, 30(4), 945-964.
[39] Jat, M. K., Garg, P. K., and Khare, D. (2008). Monitoring and modeling of urban sprawl using remote sensing and GIS techniques. International Journal of Applied Earth Observation and Geoinformation, 10(1), 26–43.
[40] Banzhaf, E., Grescho, V., and Kindler, A. (2009). Monitoring urban to peri-urban development with integrated remote sensing and GIS information: a Leipzig, Germany case study. International Journal of Remote Sensing, 30 (7), 1675–1696.
[41] Bengston, D., Fletcher, J., and Nelson, K. (2003). Public policies for managing urban growth and protecting open space: Policy instruments and lessons learned in the United States. Landscape and Urban Planning, 69, 271–286.
[42] Al-Hathloul, S.and Mughal, M. (2004). Urban growth management—The Saudi experience. Habitat International, 28, 609–623.
[43] Brueckner, J. (2007). Urban growth boundaries: An effective second-best remedy for unpriced traffic congestion? Journal of Housing Economics, 16(3-4): 263-273.
[44] Dierwechter, Y. (2008). Urban Growth Management and Its Discontents: Promises, Practices, and Geopolitics in US City-Regions. New York: Palgrave-Macmillan.
[45] Clarke, K.C., Hoppen, S., and Gaydos, L., (1997). A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. Environment and Planning B-Planning and Design, 24, 247–261.
[46] Liu, Y., and Phinn, S.R. (2003). Modelling urban development with cellular automata incorporating fuzzy-set approaches. Computers Environment and Urban System 27, 637–658.
[47] Jantz, C.A., Goetz, S.J., and Shelley, M.K. (2003). Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore–Washington metropolitan area. Environment and Planning B: Planning and Design, 30, 251–271.
[48] Han, J., Y. Hayashi, and Imura, H. (2009). Application of an integrated system dynamics and cellular automata model for urban growth assessment: A case study of Shanghai, China. Landscape and Urban Planning, 91(3), 133-141.
[49] Feng, Y. J., Liu, Y., Tong, X. H., Liu, M. L., and Deng, S. (2011). Modeling dynamic urban growth using cellular automata and particle swarm optimization rules. Landscape and Urban Planning, 102, 188-196.
[50] Stanilov, K., and Batty, M. (2011). Exploring the historical determinants of urban growth patterns through Cellular Automata. Transactions in GIS, 15(3), 253 – 271.
[51] Masser, I. (2001). Managing our urban future: the role of remote sensing and geographic information systems. Habitat International, 25(4), 503-512.
[52] Batty, M. and Howes, D. (2001).Predicting Temporal Pattern in Urban Development from Remote Imagery, in: Donnay, J.P. , Barnsley, M., Longley, P., (Eds.), Remote Sensing and Urban Analysis. Taylor and Francis, London, pp. 185–204.
[53] Howarth, P. J. and Boasson, E. (1983). Landsat digital enhancements for change detection in urban environments. Remote Sensing of Environment, 13, 149–160.
[54] Ehlers, M., Jadkowski, M. A., Howard, R. R., and Brostuen, D. E. (1990). Application of SPOT data for regional growth analysis and local planning. Photogrammetric Engineering and Remote Sensing, 56, 175–180.

[55] Green, K., Kempka, D., and Lackey, L. (1994). Using remote sensing to detect and monitor land cover and land use change. Photogrammetric Engineering and Remote Sensing, 60, 331–337.

[56] Seto, K. C., Kaufmann, R. K., and Woodcock, C. E. (2000). Landsat reveals China's farmland reserves—but they're vanishing fast. Nature, 406, p. 121.

[57] Dendoncker, N., Schmit, C., and Rounsevell, M. D. A. (2008). Exploring spatial data uncertainties in land use change scenarios. International Journal of Geographical Information Science, 22(9), 1013–1030.

[58] Fan, F., Wang, Y., Qiu, M., and Wang, Z. (2009). Evaluating the temporal and spatial urban expansion patterns of Guangzhou from 1979 to 2003 by remote sensing and GIS methods. International Journal of Geographical Information Science, 23(11), 1371–1388.

[59] Aguayo, M., Azocar, G., Wiegand, T., Wiegand, K., and Vega, C. (2007). Revealing driving forces of mid-cities urban growth patterns using spatial modeling: A case study of Los Ángeles (Chile). Ecology and Society, 12(1).

[60] Zhao, P., Lu, B., and de Roo, G. (2011). The impact of urban growth on commuting patterns in a restructuring city: Evidence from Beijing. Papers in Regional Science, 90(4), 735–754.

[61] Paez, A. and Scott, D. (2004). Spatial Statistics for Urban Analysis: A Review of Techniques with Examples. GeoJournal, 61(1), 53-67.

[62] Baumont, C., Erutr, C., and Le Gallo, J. (2004). Spatial analysis of employment and population density: the case of the agglomeration of Dijon 1999. Geographical Analysis, 36, 146–176.

[63] Orford, S. (2004). Identifying and comparing changes in the spatial concentrations of urban poverty and affluence: a case study of inner London. Computers, Environment and Urban Systems, 28 (6), 701-717.

[64] Deng, X., Huang J., Rozelle, S., and Uchida, E. (2010). Economic Growth and the Expansion of Urban Land in China. Urban Studies, 47(4), 813-843.

[65] White, R., Engelen, G., and Uljee, I. (1997). The use of constrained cellular automata for high-resolution modelling of urban land-use dynamics. Environment and Planning B: Planning and Design, 24, 323–343.

[66] Clarke, K.C., Hoppen, S., and Gaydos, L., (1997). A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. Environment and Planning B-Planning and Design, 24, 247–261.

[67] Batty, M., Xie, Y., and Sun, Z. (1999). Modeling urban dynamics through GIS-based cellular automata. Computer Environment and Urban System. 23, 205–233.

[68] Al-Ahmadi, K., See, L. M., Heppenstall, A. J., and Hogg, J. (2009). Calibration of a fuzzy cellular automata model of urban dynamics in Saudi Arabia. Ecological Complexity, 6(2), 80-101.

[69] de Soto, H. 1992: Marktwirtschaft von unten – Die unsichtbare Revolution in Entwicklungslandern. Orell Fussli Verlag, Zurich, Koln.

[70] Durand-Lasserve, A.; Selod, H. 2007: The formalisation of urban land tenure in developing countries. Paper presented at World Bank's 2007 Urban Research Symposium, May 14th-16th 2007, Washington DC.

[71] Taher Osman, Prasanna Divigalpitiya, Takafumi Arima. Effect of Governmental Housing Regulations on the Egyptian Housing Market: Focusing on Greater Cairo Metropolitan Region, Journal of Architecture and urban Design, Kyushu University, No. 28, pp. 1- 9, July 2015.

[72] ILO (International Labour Organization) 2007: The decent work agenda in Africa: 2007–2015. Report of the Director-General to the Eleventh African Regional Meeting, Addis Ababa, April 2007. International Labour Office, Geneva.

[73] ILO (International Labour Organization) 2005: World employment report 2004-05 -Employment, productivity and poverty reduction. International Labour Office, Geneva.

[74] ILO (International Labour Organization) 2002: Women and men in the informal economy: A statistical picture. International Labour Office, Geneva.

[75] ILO (International Labour Organization) 1992: World labour report 1992. International Labour Office, Geneva.

[76] ILO (International Labour Organization) 2006: Changing patterns in the world of work, Report of the Director-General, International Labour Conference, 95th Session, Geneva.

[77] ILO-JASPA (International Labour Organization, Jobs and Skills Programme for Africa) 1992: African employment report 1992 - Jobs and skills programme for Africa, International Labour Organization, Addis Ababa.

[78] Barnsley, M. & Barr, S., 1996. Inferring urban land use from satellite sensor images using kernel based spatial reclassification. Photogrammetric Engineering and Remote Sensing, 62(8), 949-958.

[79] MOP and GTZ, 2004. (Ministry of Planning - German Technical and Financial Cooperation), New Practice of Participatory Local - Development in Egypt's Urban Areas, Policy Paper, Egypt.

[80] UNDP. 2004. Egypt Human Development Report 2004; major output of the Human Development Project, executed by the Institute of National Planning under technical cooperation with the United Nations Development Program (UNDP), Egypt.

[81] Geoghegan, J., Wainger, L.A. & Bockstael, N.E., 1997. Spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS. Ecological Economics, 23(3), 251-264.

[82] Luck, M. & Wu, J., 2002. A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA. Landscape Ecology, 17(4), 327-339.

[83] Andersson, E., Barthel, S. & Ahrne, K., 2007. Measuring social-ecological dynamics behand the generation of ecosystem services. Ecological Applications, 17(5), 1267-1278.

[84] Collins, J.P. et al., 2000. A new urban ecology: Modeling human communities as integral parts of ecosystems poses special problems for the development and testing of ecological theory. American Scientist, 88, 416-425.

[85] York, A.M. et al., 2009. Landscape fragmentation under rapid urbanization. UGEC Viewpoints, 2, 20- 24.

[86] O'Neill, R.V. et al., 1988. Indices of landscape pattern. Landscape Ecology, 1(3), 153-162.

[87] Wu, J. et al., 2002. Empirical patterns of the effects of changing scale on landscape metrics. Landscape Ecology, 17(8), 761-782.

[88] Li, H. & Wu, J., 2004. Use and misuse of landscape indices. Landscape Ecology, 19(4), 389-399.

[89] Wu, J., 2004. Effects of changing scale on landscape pattern analysis: scaling relations. Landscape Ecology, 19(2), 125-138.

[90] Ji, W. et al., 2006. Characterizing urban sprawl using multi-stage remote sensing images and landscape metrics. Computers, Environment and Urban Systems, 30(6), 861-879.

[91] Zhu, M. et al., 2006. The effects of sensor spatial resolution and changing grain size on fragmentation indices in urban landscape. International Journal of Remote Sensing, 27(21), 4791.

[92] Buyantuyev, A. & Wu, J., 2007. Effects of thematic resolution on landscape pattern analysis. Landscape Ecology, 22(1), 7-13.

[93] Shao, G. & Wu, J., 2008. On the accuracy of landscape pattern analysis using remote sensing data. Landscape Ecology, 23(5), 505-511.

[94] Cifaldi, R.L. et al., 2004. Spatial patterns in land cover of exurbanizing watersheds in southeastern Michigan. Landscape and Urban Planning, 66(2), 107-123.

[95] Furberg, D. & Ban, Y., 2008. Satellite monitoring of urban sprawl and assessing the impact of land cover changes in the Greater Toronto Area. In The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B8. Beijing 2008. Beijing, China, pp. 131-136.

[96] Furberg, D. & Ban, Y., 2009. Satellite monitoring and impact assessment of urban growth in Stockholm, Sweden between 1986 and 2006. In 29th Annual EARSel Symposium. Chania, Greece.

[97] Herold, M., Scepan, J. & Clarke, K.C., 2002. The use of remote sensing and landscape metrics to describe structures and changes in urban land uses. Environment and Planning A, 34(8), 1443 – 1458.

[98] Seto, K.C. & Fragkias, M., 2005. Quantifying Spatiotemporal Patterns of Urban Land-use Change in Four Cities of China with Time Series Landscape Metrics. Landscape Ecology, 20(7), 871-888.

[99] Herold, M., Couclelis, H. & Clarke, K.C., 2005. The role of spatial metrics in the analysis and modeling of urban land use change. Computers, Environment and Urban Systems, 29(4), 369-399.

[100] Zhang, L. et al., 2004. RETRACTED: A GIS-based gradient analysis of urban landscape pattern of Shanghai metropolitan area, China. Landscape and Urban Planning, 69(1), 1-16.

[101] Deng, J.S. et al., 2009. Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. Landscape and Urban Planning, 92(3-4), 187-198.

[102] Tang, J., Wang, L. & Yao, Z., 2008. Analyses of urban landscape dynamics using multi-temporal satellite images: A comparison of two petroleum-oriented cities. Landscape and Urban Planning, 87(4), 269-278.
[103] Johnsson, K., 1994, Segment-based land-use classification from SPOT satellite data. Photogrammetric Engineering and Remote Sensing, 60, 47–53.
[104] Carlson, T. N., 2003, Applications of remote sensing to urban problems. Remote Sensing of Environment, 86, 273–274.
[105] Lillesand, T. M., Kiefer, R. W. and Chipman, J. W., 2008, Remote Sensing and Image Interpretation. New York: John Wiley & Sons, Inc.
[106] Cadenasso, M. L., Pickett, S. T. A. and Schwarz, K., 2007, spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification. Frontiers in Ecology and Environment, 5, 80-88.
[107] Maktav, D., Erbek, F. S. and Jurgens, C., 2005, Remote sensing of urban areas. International Journal of Remote Sensing, 26, 655–659.
[108] Thapa, R. B. and Murayama, Y., 2007, Image classification techniques in mapping urban landscape: A case study of Tsukuba city using AVNIR-2 sensor data. Tsukuba Geoenvironmental Sciences, 3, 3-10.
[109] Carlson, T. N. and Arthur, T. S., 2000, The impact of land use - land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective. Global and Planetary Change, 25, 49–65.
[110] Gatrell, J. D. and Jensen, R. R., 2008, Sociospatial applications of remote sensing in urban environments. Geography Compass, 2, 728–743.
[111] Lo, C. P. and Choi, J., 2004, A hybrid approach to urban land use/cover mapping using Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images. International Journal of Remote Sensing, 25, 1687-2700.
[112] Prenzel, B. and Treitz, P., 2005, Comparison of function- and structure-based schemes for classification of remotely sensed data. International Journal of Remote Sensing, 26, 543–561.
[113] Ozkan, C. and Erbek, F. S., 2005, Comparing feature extraction techniques for urban landuse classification. International Journal of Remote Sensing, 26, 747–757.
[114] Carvalho, J., Soares, A. and Bio, A., 2006, Improving satellite images classification using remote and ground data integration by means of stochastic simulation. International Journal of Remote Sensing, 27, 3375–3386.
[115] Zhang, J. and Foody, G. M., 2001, Fully-fuzzy supervised classification of sub-urban land cover from remotely sensed imagery: statistical and artificial neural network approaches. International Journal of Remote Sensing, 22, 615-628.
[116] Zang, S. and Huang, X., 2006, An aggregated multivariate regression land-use model and its application to land-use change processes in the Daqing region (northeast China). Ecological Modelling, 193, 503-516.
[117] Lambin, E. F., Turner II, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O., Dirzo, R., Fischer, G., Folke, C., George, P. S., Homewood, K., Imbernon, J., Leemans, R., Li, X. B., Moran, E. F., Mortimore, M., Ramakrishnan, P. S., Richards, J. F., Skanes, H., Stone, G. D., Svedin, U., Veldkamp, A.,Vogel, C. and Xu, J. C., 2001, The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change, 11, 261-269.
[118] Hietel, E., Waldhardt, R. and Otte, A., 2005, Linking socio-economic factors, environment and land cover in the German Highlands, 1945–1999. Journal of Environmental Management, 75, 133–143.
[119] Mottet, A., Ladet, S., Coque, N. and Gibon, A., 2006, Agricultural land-use change and its drivers in mountain landscapes: A case study in the Pyrenees. Agriculture, Ecosystems and Environment, 114, 296–310.
[120] Dale, V. H., 1997, The relationship between land-use change and climate change. Ecological Applications, 7, 753-769.
[121] Watson, R. T., Nobel, I. R., Bolin, B., Ravindranath, N. H., Verado, D. J. and Dokken, D. J. (eds.), 2000, Land use, land-use change, and forestry. A Special Report of the Intergovernmental Panel on Climatic Change, Cambridge University Press, Cambridge.

[122] Serneels, S. and Lambin, E. F., 2001, Proximate causes of land use change in Narok district Kenya: a spatial statistical model. Agriculture, Ecosystems and Environment, 85, 65–81.
[123] Nelson, G. C., Harris, V. and Stone, S. W., 2001, Deforestation, land use, and property rights: empirical evidence from Darien, Panama. Land Economics, 77, 187-205.
[124] Pontius, R. G. and Schneider, L. C., 2001, Land-use change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems and Environment, 85, 239-248.
[125] Pijanowski, B. C., Brown, D. G., Shellito, B. A. and Manik, G. A., 2002, Using neural networks and GIS to forecast land use changes: a land transformation model. Computers, Environment and Urban Systems, 26, 553-575.
[126] Turner, M. D., 2003, Methodological reflections on the use of remote sensing and geographic information science in human ecological research. Human Ecology, 31, 255–279.
[127] Verburg, P. H., Ritsema van Eck, J., de Nijs, T., Schot, P. and Dijst, M., 2004, Determinants of land-use change patterns in the Netherlands. Environment and Planning B, 31, 125-150.
[128] Briassoulis, H., 2000, Analysis of land use change: Theoretical and modeling approaches. In The web-book of regional science, W.R. Jackson (ed.), Regional Research Institute, West Virginia University, USA.
[129] Liu, J., 2001, Integrating ecology with human demography, behavior and socioeconomics: needs and approaches. Ecological Modelling, 140, 1–8.
[130] Naveh, Z., 2001, Ten major premises for a holistic conception of multifunctional landscapes. Landscape and Urban Planning, 57, 269–284.
[131] Lambin, E. F., Geist, H. J. and Lepers, E., 2003, Dynamics of land-use and land-cover change in tropical regions. Annual Review of Environment and Resources, 28, 205-241.
[132] Almeida, C. M., Batty, M., Monteiro, A. M. V., Camara, G. , Soares-Filho, B. S., Cerqueira, G. C. and Pennachin, C. L., 2003, Stochastic cellular automata modeling of urban land use dynamics: empirical development and estimation. Computers, Environment and Urban Systems, 27, 481–509.
[133] Bray, D. B., Ellis, E. A., Armijo-Canto, N. and Beck, C. T., 2004, The institutional drivers of sustainable landscapes: a case study of the 'Mayan Zone' in Quintana Roo, Mexico. Land Use Policy, 21, 333–346.
[134] Antrop, M., 2005, Why landscapes of the past are important for the future. Landscape and Urban Planning, 70, 21-34.
[135] Tian, G., Liu, J., Xie, Y., Yang, Z., Zhuang, D. and Niu, Z., 2005, Analysis of spatiotemporal dynamic pattern and driving forces of urban land in China in 1990s using TM images and GIS. Cities, 22, 400–410.
[136] Saaty, T. L., 1980, The Analytic Hierarchy Process. New York: McGraw-Hill.
[137] Banai-Kashani, A. R., 1990, dealing with uncertainty and fuzziness in development planning: a simulation of high-technology industrial location decision-making by the analytic hierarchy process. Environment and Planning A, 22, 1183-1203.
[138] Malczewski, J., 1999, GIS and Multicriteria Decision Analysis. New York: John Wiley &Sons.
[139] Kauko, T., 2004, Sign value, topophilia, and the locational component in property prices. Environment and Planning A, 36, pp. 859-878.
[140] Saaty, T. L. and Vargas, L. G., 2001, Models, Methods, Concepts & Applications of the Analytic Hierarchy Process. Dordrecht: Kluwer Academic Publishers.
[141] Cabral, P. & Zamyatin, A., 2006. Three land change models for urban dynamics analysis in Sintra-Cascais area. In 1st EARSeL Workshop of the SIG Urban Remote Sensing. Humboldt-Universität zu Berlin.
[142] Johnson, M.P., 2001. Environmental impacts of urban sprawl: a survey of the literature and proposed research agenda. Environment and Planning A, 33(4), 717 – 735.
[143] Overmars, K. P. and Verburg, P. H., 2005, Analysis of land use drivers at the watershed and household level: Linking two paradigms at the Philippine forest fringe. International Journal of Geographical Information Sciences, 19, 125-152.

[144] Koomen, E. and Stillwell, J. 2007. Modelling land-use change: Theories and methods. In Modelling Land-Use Change, E. Koomen, Stillwell, J., Bakema, A. and Scholten, H.J., (eds.), GeoJournal Library, 90, pp. 1-21, Dordrecht: Springer.
[145] Angelsen, A. and Kaimowitz, D., 1999, rethinking the causes of deforestation: lessons from economicmodels. TheWorld Bank Observer, 14, 73-98.
[146] Walsh, S. J., Crawford, T. W., Crews-Meyer, K. A. and Welsh, W. F., 2001, A multi scale analysis of land use, land cover change and NDVI variation in Nang Rong District, Northeast Thailand. Agriculture, Ecosystems and Environment, 85, 47-64.
[147] Krugman, P., 1999, The role of geography in development. International Regional Science Review, 22, 142-161.
[148] Torrens, P. M. and O'Sullivan, D., 2001, Cellular automata and urban simulation: where do we go from here? Environment and Planning B, 28, 163-168.
[149] White, R. & Engelen, G., 2000. High-resolution integrated modelling of the spatial dynamics of urban and regional systems. Computers, Environment and Urban Systems, 24(5), 383-400.
[150] Wu, F., 1999, GIS-based simulation as an exploratory analysis for space-time processes. Journal of Geographical Systems, 1, 199-218.
[151] Dietzel, C., Herold, M., Hemphill, J. J. and Clarke, K. C., 2005, Spatio-temporal dynamics in California's central valley: Empirical links to urban theory. International Journal of Geographical Information Science, 19, 175-195.
[152] Torrens, P. M., 2006, simulating sprawl. Annals of the Association of American Geographers, 96, 248-275.
[153] Zhao, Y. and Murayama, Y., 2006, A method to model neighborhood interactions in geosimulation of urbanization processes. In Geographic Information Science,
[154] Lambin, E.F., 2004. Modeling land-use change. In Environmental Modelling: Finding Simplicity in Complexity Edited by John Wainwright & Mark Mulligan. John Wiley & Sons Inc., p. 430.
[155] Clarke, K.C. & Gaydos, L.J., 1998. Loose-coupling a cellular automaton model and GIS: long-term urban growth prediction for San Francisco and Washington/Baltimore. International Journal of Geographical Information Science, 12(7), 699.
[156] Conway, T.M. & Lathrop, R.G., 2005. Modeling the Ecological Consequences of Land-Use Policies in an Urbanizing Region. Environmental Management, 35(3), 278-291.
[157] Shen, Q. et al., 2009. A system dynamics model for the sustainable land use planning and development. Habitat International, 33(1), 15-25.
[158] He, C. et al., 2006. Modeling urban expansion scenarios by coupling cellular automata model and system dynamic model in Beijing, China. Applied Geography, 26(3-4), 323-345.
[159] Li, X. & Yeh, A.G., 2004. Analyzing spatial restructuring of land use patterns in a fast growing region using remote sensing and GIS. Landscape and Urban Planning, 69(4), 335-354.
[160] Li, X. & Yeh, A.G., 2001. Calibration of cellular automata by using neural networks for the simulation of complex urban systems. Environment and Planning A, 33(8), 1445 – 1462.
[161] Li, X. & Yeh, A.G., 2002. Neural-network-based cellular automata for simulating multiple land use changes using GIS - PB - Taylor & Francis. International Journal of Geographical Information Science, 16(4), 323.
[162] RUMELHART, D.E., HINTON, G.E. and WILLIAMS, R.J., 1986, learning representations by back-propagation errors. Nature, 323, 533-536.
[163] Theobald, D. M., & Hobbs, N. T. (1998). Forecasting rural land-use change: a comparison of regression- and spatial transition-based models. Geographical & Environmental Modelling, 2(1), 65-82.
[164] Batty, M. & Xie, Y., 1994. From cells to cities. Environment and Planning B: Planning and Design, 21(7), s31 – s48.
[165] Hagoort, M., Geertman, S. & Ottens, H., 2008. Spatial externalities, neighbourhood rules and CA land-use modelling. Annals of Regional Science, 42(1), 39-56.
[166] Solecki, W.D. & Oliveri, C., 2004. Downscaling climate change scenarios in an urban land use change model. Journal of Environmental Management, 72(1-2), 105-115.

[167] Wu & Webster, 1998. Simulation of land development through the integration of cellular automata and multicriteria evaluation. Environment and Planning B: Planning and Design, 25(1), 103 – 126.

[168] Jiao, J., 2003. Transition rule elicitation for urban cellular automata models: Case study, Wuhan, China. , International Institute for Geo-Information Science and Earth Observation. Enschede, the Nertherland.

[169] Houet, T. & Hubert-Moy, L., 2006. Modelling and projecting land-use and land-cover changes with a Cellular Automaton in considering landscape trajectories: An improvement for simulation of plausible future states. EARSeL eProceedings, 5(1), 63-76.

[170] Sun, H., Forsythe, W. & Waters, N., 2007. Modeling Urban Land Use Change and Urban Sprawl: Calgary, Alberta, Canada. Networks and Spatial Economics, 7(4), 353-376.

[171] Couclelis, H., 1988. Of mice and men: what rodent populations can teach us about complex spatial dynamics. Environment and Planning A, 20(1), 99 – 109.

[172] Matsinos, Y.G. & Troumbis, A.Y., 2002. Modeling competition, dispersal and effects of disturbance in the dynamics of a grassland community using a cellular automaton model. Ecological Modelling, 149(1-2), 71-83.

[173] Morley, P.D. & Chang, J., 2004. Critical behavior in cellular automata animal disease transmission model. International Journal of Modern Physics C, 15(1), 149-162.

[174] Balzter, H., Braun, P.W. & Köhler, W., 1998. Cellular automata models for vegetation dynamics. Ecological Modelling, 107(2-3), 113-125.

[175] Poska, A. et al., 2008. Using quantitative pollen-based land-cover estimations and a spatial CA_Markov model to reconstruct the development of cultural landscape at Rõuge, South Estonia. Vegetation History and Archaeobotany, 17(5), 527-541.

[176] Soares-Filho, B.S., Coutinho Cerqueira, G. & Lopes Pennachin, C., 2002. DINAMICA-a stochastic cellular automata model designed to simulate the landscape dynamics in an Amazonian colonization frontier. Ecological Modelling, 154(3), 217-235.

[177] Bone, C., Dragicevic, S. & Roberts, A., 2006. A fuzzy-constrained cellular automata model of forest insect infestations. Ecological Modelling, 192(1-2), 107-125.

[178] Lett, C., Silber, C. & Barret, N., 1999. Comparison of a cellular automata network and an individual based model for the simulation of forest dynamics. Ecological Modelling, 121(2-3), 277-293.

[179] Ito, A., 2005. Modelling of carbon cycle and fire regime in an east Siberian larch forest. Ecological Modelling, 187(2-3), 121-139.

[180] Yassemi, S., Dragicevic, S. & Schmidt, M., 2008. Design and implementation of an integrated GISbased cellular automata model to characterize forest fire behaviour. Ecological Modelling, 210(1-2), 71-84.

[181] Caruso, G. et al., 2007. Spatial configurations in a periurban city. A cellular automata-based microeconomic model. Regional Science and Urban Economics, 37(5), 542-567.

[182] Alberti, M. & Waddell, P., 2000. An integrated urban development and ecological simulation model. Integrated Assessment, 1(3), 215-227.

[183] Barredo, J.I. et al., 2003. Modelling dynamic spatial processes: simulation of urban future scenarios through cellular automata. Landscape and Urban Planning, 64(3), 145-160.

[184] Luo, P. et al., 2002. The study on extended cellular automata based on relational database and the spatio - temporal simulating (In Chinese). Geography and Territorial Research, 18(3), 8-12.

[185] Zhang, Y., Chen, Y. & Li, J., 2008. Study on the dynamic city model based on cellular automata and population condition (In Chinese). Journal of Image and Graphics, 12(8), 1483-1488.

[186] Yang, Q. & Li, X., 2006. Dynamic constrained CA model for simulating complex urban systems (In Chinese). Geography and Geo-Information Science, 22(5), 10-15.

[187] O'Sullivan, D. & M.Torrens, P., 2000. Cellular models of urban systems, Centre for Advanced Spatial Analysis University College London. Available at: http://www.casa.ucl.ac.uk/cellularmodels.pdf.

[188] Liu, X. et al., 2008. Simulating complex urban development using kernel-based non-linear cellular automata. Ecological Modelling, 211(1-2), 169-181.

[189] Baker, W. L. A review of models of landscape change. Landscape Ecology, v. 2, n. 2, p. 111-133, 1989.

[190] Muller, R. M. and Middleton, J. (1994). A Markov model of land-use change dynamics in the Niagara region, Ontario, Canada. Landscape Ecology 9, 151–157.

[191] Weng, Q., 2002. Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. Journal of environmental management, 64(3), pp.273–284.

[192] Bell, E. J. (1974).Markov analysis of land use change: an application of stochastic processes to remotely sensed data. Socio-Econ Planning Science 8, 311–316.

[193] Zhang, Q. et al., 2011. Simulation and analysis of urban growth scenarios for the Greater Shanghai Area, China. Computers, Environment and Urban Systems, 35(2), pp.126–139. Available at: http://dx.doi.org/10.1016/j.compenvurbsys.2010.12.002.

2. Government policies to meet the rapid sprawl of low-cost informal housing areas

* This chapter is based on the following paper:

Osman, T., Divigalpitiya, P. & Arima, T., 2015. Effect of governmental housing regulations on the Egyptian housing market: Focusing on greater Cairo metropolitan region. J. Archit. Urban Des, 28, pp.1-9.Available at: http://ci.nii.ac.jp/naid/40020624866/

Abstract

The housing issue in Greater Cairo metropolitan region (GCMR)'s has continued despite of the numerous policies that the government has introduced during the last 70 years. This research discusses housing policies changes and their effects on the housing issue in GCMR. Primary data were derived through questionnaire survey and secondary data from national censuses. The results find that the change in the general state policies did success in attracting more investments for public housing of low-income residents but failed to end the phenomenon of vacant housing or attract slums residents to new urban centers (NUC).

Keywords: *Housing regulations, Housing demand, Housing supply, NUC, GCMR, Egypt*

2.1 Introduction

Egyptian Centre for Housing Rights (ECHR) stated that the Expanding income inequalities between the top 20% and the poorest 20% of residents have deteriorated both poverty issues and concerning housing issues. As an outcome of this issue in 1992 about 19.4% of Greater Cairo Metropolitan Region (GCMR) urban residents, or nearly 2.5 million people, were living in informal settlements [1,2].These numbers matched with a similar ratio in 1974, when GCMR's total population were smaller.

The hosing issue mainly occurs because of the inability of newly married to pay for suitable housing. They are compelled to live with their families, generating hosing crisis on both the exciting and the new families. Whereas rents might be affordable up-front key money usually prevent many new families from entering into the housing market. Zurayk and Shorter ,1988 [3] have shown that one-third of GCMR's newly married live with their families, with proportion dropping to 20% once they have their second child. Ibrahim and Ibrahim, 2003 [4, 5] mentioned that the lower middle classes, which represents the larger number of GCMR's residents, are mostly unable to pay for appropriate houses.

Despite 70 years of attempts by the government to help low income families to find an appropriate houses particularly in GCMR, as it has being the case in most Egyptian cities and villages, unplanned settlements around GCMR sheltered more than 7 million inhabitants in 1998 [6,7]. As of 2006, informal settlements were estimated to house more than 65% of the population of GCMR (10.5 out of 16.2 million inhabitants) [8,9], and the rate of population growth in these areas is higher than other cities averages, with an increase of 2% between 1996 and 2006 [7].

On the other hand, number of vacant housing units in GCMR was 5.4 million units that located in low, middle, and high class GCMR districts (Figure 2.2 and Figure 2.3).Owners of vacant units refrain to rent or buy their housing units for some reasons such as speculations to increase prices, keeping for sons married in future, and real estate is the best way to keep their savings in Egypt away of inflation and taxes [5, 10, 11]. On the other hand, the housing units prices in existing formal districts of GCMR is not attainable for large percentage of Egyptian people who seeks for new house since the large gap among community incomes and the high rates of increasing prices of formal units [7,12]. So, people find the proper way to find a housing unit in the unplanned urban expansions in agricultural lands surround GCMR (Figure 2.3).

In fact, there are no housing in GCMR today that are affordable to the normal residents to rent. Low-income residents live in congested basements, rooftop dwellings, or in other inappropriate living quarters [1]. Housing shortage pushed by economic restrictions that has set a high price on the capability to form a nuclear household [13], with a sustained combat to collect resources for purchasing a room or a flat which contribute to put off in marriage preparations among young people. So their families and new families have to live jointly, agreeing to a lesser standard of housing as one way to overcome housing crisis1 [11, 14].

This research seeks to find the effect of accumulated changes of governmental housing policies to meet the housing problem in GCMR. We focus on the visible facts of housing dilemma in GCMR which represents in, 65 % of the 17 million of Cairo residents' lives in slums while 30.5 % of total residential units are vacant in 2006.

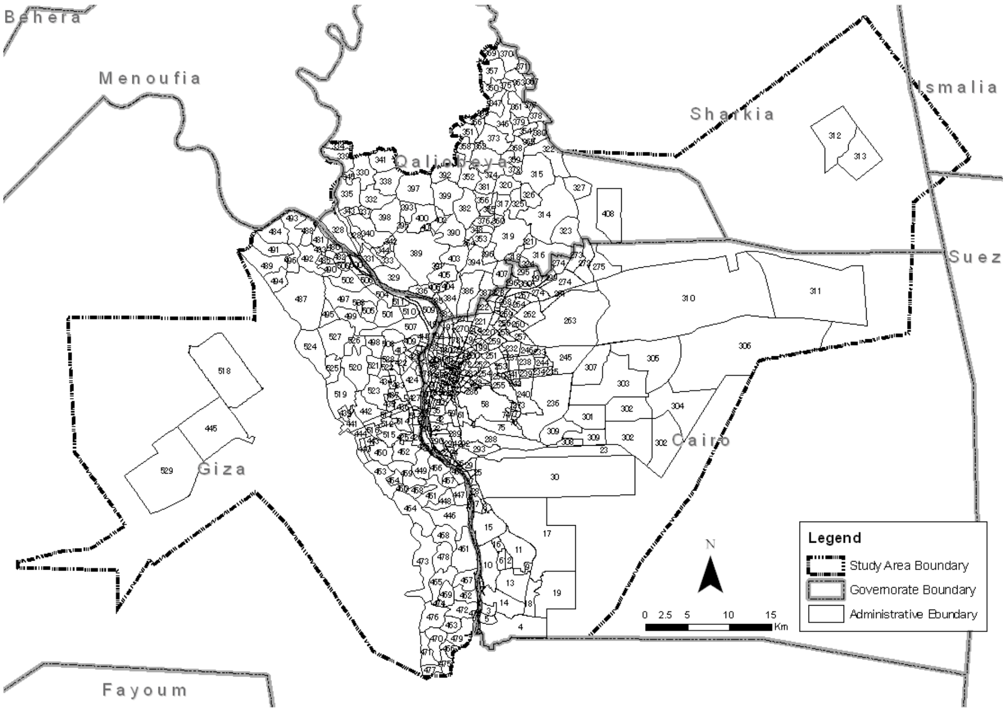


Figure 2.1 Location of GCMR within Egypt

Source:JICA,2008 [8]

2.2 Study Area

GCMR is comprised of the whole of Cairo Governorate and the urban areas of Giza Governorate (west of the Nile) and Qaliubia Governorate (north of Cairo Governorate). Governorates are the major municipal institutions in Egypt. And there is no macro-administrative structure that constitutes a GCMR as a single administrative structure. But, there are service institutions for wastewater, water, and public transport whose service area covers the whole GCMR. The "GCMR" has been founded with urban planning objectives under General Organization for Physical Planning (GOPP). Cairo is not only the Political capital of Egypt, but also its service, social, economic, and administrative hub [2,8].

In the research works of metropolitan areas in developing countries, GCMR is usually mentioned as symbol of congestion, slum dwellings and housing issues among the urban poor. Specially, shanty houses, and informal vertical expansions of dwelling house blocks are unusual in Egypt's capital metropolitan region. As the biggest city in Africa and the Middle East, Cairo, has long history of severe and a concerning housing issue. According to 2006 census (CAPMAS) [9], it was found that GCMR core, outskirts and exurbs have 17,600,000 residents. Since the 1996 census, GCMR has added around 3,000,000 people. The city itself has 7,800,000 residents. Whilst Giza contributes nearly 5,800,000 residents to GCMR's population, nearly 3,900,000 live in Qualubya governorate [9, 14]. Over the last century up to 1996 the city's residents have grown four times but the area of urban units has expanded only twofold [8,15].

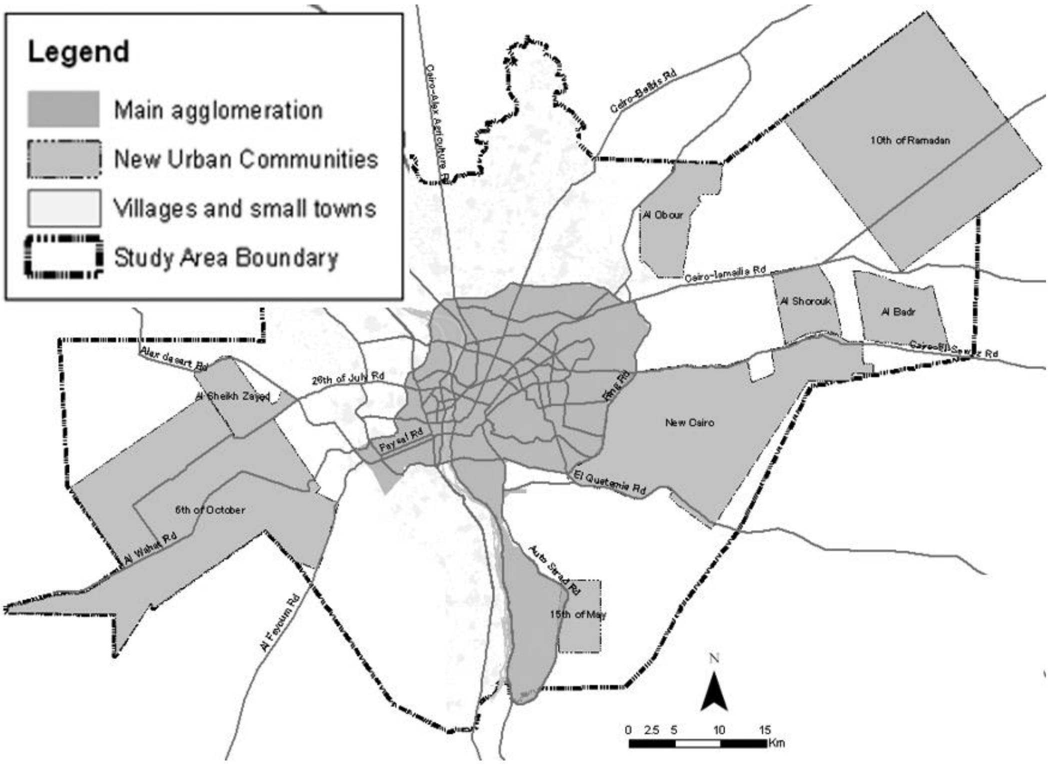


Figure 2.2 NUC within Main Urban Areas at GCMR

Source:JICA,2008 [8]

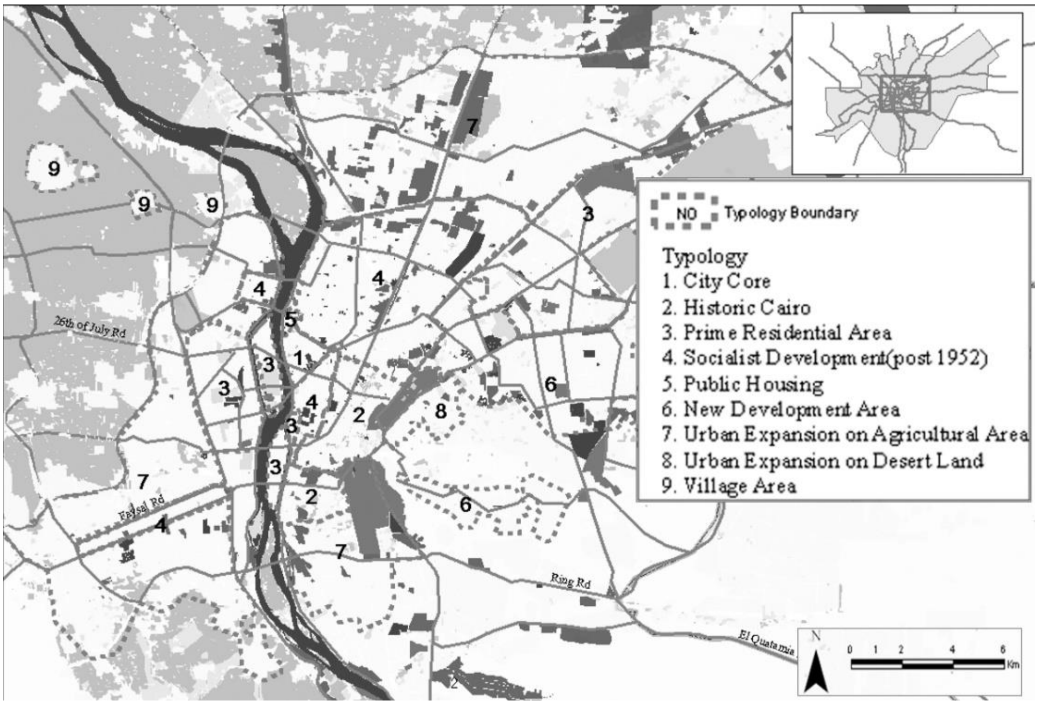


Figure 2.3 Sample of the Housing Units Classes in GCMR

Source:JICA,2008 [8]

2.3 Methods and Data

The main goal of this study was to investigate the insufficiencies and sufficiencies of official government regulations and laws to meet the housing issue in Egypt from 2001-2013 focusing on GCMR as case study. To achieve this goal we followed following integrated method:

A. A questionnaire survey conducted with professional housing experts in the Egyptian housing market.

B. Classify the respondents' answers under main topics to facilitate comparing survey results with the previous researches.

C. Compared results of questionnaire survey with the previous researches conducted to study housing issue for the last 70.

D. Analyzed the information given by the professional experts who are working housing and planning field using the survey, and previous research don by various researchers. These analyses provided an integrated image of the nature of housing issue in GCMR.

The questionnaire survey was conducted from April 2013- September 2013 with samples included professional experts of Housing market included: official dwelling houses authorities, planners, real property agents, land building contractors, and major property association's presidents. A non-probabilistic purposive sampling method was used to select respondents for the questionnaire. Creswell and Clark (2007) [16] mentioned that purposive sampling is useful in urban planning to select respondents who have background knowledge of central phenomenon or key concept being discussed. In this case, people with professional experience in the supplying dwelling houses were considered as experts.

The samples were chosen from the corporations that play related functions in dwelling houses supplying. From the Ministry of Housing and Urban Development in GCMR, the director in the regional planning department has participated. Two samples from each of the following Official housing Authorities in Egypt were asked: The Ministry of Planning, National Investment Bank, Ministry of Housing and New Urban Communities, the Central Authority for International Development, and the New Urban Communities Authority, General Organization for Physical Planning (GOPP), the Egyptian Cooperative, General Building and Housing Cooperative Authority, and housing cooperative societies.

We prepared a questionnaire with one question with open answer "although 70 years of housing policies and regulations mainly to help low class income peoples, why 65% of GCMR population are living in slums?" The questionnaire has attached a summary of the housing laws during last 70 years (Table 2.1). The respondents asked to submit their responses in any number of words, adding forms or tables, and documents. Respondents submitted their responses in different forms with sketches, table, and references for related important projects in their point of view.

Questionnaires were sent out to employees through their employee's head offices and also retrieved from them. In all, a total of 857 questionnaires was distributed and 642 were returned with answers. Five out of 215 questionnaires returned were void because of deficient answers. The survey concluded with 642 valid questionnaires, which represent a proportion of return 74.9%. This sample size is regarded to be appropriate and for this study. Taylor, 2012 [17] mentioned that, for an uncertainty target residents, 300 - 500 samples could work as long as the survey is representative.

The contents of the respondents answers were quiet similar, we summarized it under main titles and then added some related information from related literatures to be more explained for the readers. At the time of the field-work, there were 4 Governorates institutions' authorities, and 529 Local administrative units in the research area. The samples of public sector employees in the study area were not collected since the failure to access employee groups. Some of the regional authorities in GCMR are divisions of national institutions and they needed an official approval from head office to participate questioner survey.

A multi-stage sampling logic was chosen to select samples from residents. Firstly, lists of institutions that come under the GCMR government were gathered in to three clusters. The second stage those institutions were stratified in to classes of professions and relevant functions. From each stratum, institutions were indiscriminately chosen and letters were sent to them asking permission to perform the survey. From the local municipality cluster, 8 institutions, and 10 from the GCMR sub-Governments cluster accepted the invitation. We have summarized the respondents' answers under a number of main topics (Table 2.2). We had to eliminate number of responses from the list since the small amount of samples. The number of eliminated answers were 28 answers concentrated in mainly three topics: the failure to connect informal housing with infrastructure and amenities, Failure to decrease areas of informal housing zones, and failure to decrease the corruption in GCMR housing authorities in allocating housing budgets for urban areas.

2.4 Egyptian Housing Regulations 1940-2001

Before 1940s, Egyptian dwelling market was largely owned by foreign owners, until the first rent control legislation in 1947; freezing rents at their 1941 level and preventing owners from deporting their leaseholders. The most intemperate alterations to the law took place from 1952 to1965. In line with the 1952 revolution's populist spirit, formerly fixed rents were decreased further and controls were expanded to cover newer units. Since 1952 the state has interfered in the establishing of social dwelling houses, such as workers dwelling house projects around industrial centers in GCMR [1, 18]. In 1960s, the government participated in the building of low-cost public housing for the middle classes on GCMR [14, 19].

2.4.1 The Rent Control Legislation, 1962

The 1962 rent control legislation permitted the continuation of ownership from the renter to their inheritors. From 1965 to 1975, the construction of public dwelling houses decreased to less than one-third of the former decade. With high rates of population growth and sustained urbanization, the gap between demand and supply for both private and public dwelling houses has increased. Starting from 1965 a governmental 5 years plan has strengthened the rent control by lowering 20% of the rental price of dwelling house units established after 1944. This created the environment for decline of the rental dwelling house supplies as servicing expenses override the rents [5,14,20].

2.4.2 Open Door Economic policy, 1975

After 1975 as an outcome of the open door economic policy (Infitah) and privatization schemes, the government declared that it would only be in charge of building of low-cost dwelling houses and that the private sector will be responsible for the supplying of other house units. So, the government declared the law 43/1974 which targeted at Arab and foreign capitals, private sector corporations worked in the building of upper and middle-class houses, benefiting from different tax exemptions. For the nest 5–8 years, tax exceptions of 10–15 years for house construction has established new urban communities [11, 21]. Based on that, There was a considerable growth in public housing, and nearly 30,900 units per year were built [14, 22].

2.4.3 Dwelling Houses Law, 1981

In 1981 the government introduced the dwelling houses law of 1981 whereby one-third of all dwelling house units within each residential building would be available for sale. This law stated that all dwelling house investors can obtain low interest loans [19]. Later dwelling houses laws decree No. 2/1986 gave leaseholders the right to get a new, dissociate tenancy agreement from the proprietor [5, 19].

2.4.4 Macro-Economic Policies of 1990s

During 1990s fundamental modification of policies and economic reformation at macro level have worsened the dwelling houses problem for lower and middle class residents of the community, as most public dwelling house investment was directed at supplying of dwelling house units that become unaffordable to the larger proportion of the residents. Consequently, high rates of vacancies were observed within low- cost condominiums in The New urban community (NUC). Cooperative loans and building permits were mainly helped middle and high-class clusters, as the private capital has triggered substantial growth in land prices. The sustained growth in land speculation within and around urban centers caused increasing land prices, leaving low and middle income urban dwellers with no affordable alternative other than joining the informal dwelling house market [5,14].

2.4.5 Rental Law No. 4, 1996

In 1996, Rental Law No. 4 created two major transformations in the Egyptian real estate market. Firstly, it ended the risky inherit of assets from the renter to their inheritors. Secondly, it specified that the rent contracts must be restricted to a specific time period, without any bonds on price, other than that has formerly agreed upon. Article 14 of the 1996 law created instantaneous rent growth with a 10 % yearly growth of housing units for five consecutive years [1,11,21].

2.4.6 The Real Property Investments Law 2001

In 2001, new trend of housing regulations, The Real property Investments Law (148/2001) – better known as the Mortgage law. This law is introduced to provide long-term loans for purchasing, building and renewing real property at up to 90% of the price of the housing unit. The new mortgage law defined the widespread pro-renter culture, permitting banks to reclaim real estates and deport proprietors who default. Mortgage loans provide up to 90% of the price of the asset, with a monthly pay at nearly 40% of the debtor's net monthly income, and with repayment duration of 25 to 30 years [8,11,14].

Table 2.1 Egyptian Dwelling Houses Laws and Regulations 1941- 2001

Date	Legislation	Activity
2001-Now	Law No148/2001	Mortgage Law is prepared to supply incommodious long-term funds for purchasing, constructing and renewing real property at up to 90% of the estimation of the dwelling houses unit.
1996	Law No. 4/1996	Article 14 of the bill states instantaneous rent grows on the fundamentals of the year of the building was done (rents grows by 10% for units done before 1 January 1944, by 3% for condominiums in buildings accomplished between 9 September 1977 and December 1996). Rents on all units are then to grows yearly by 10% for five sequential years, after which the market is presumed to take over
1992	Law No. 25/1992	Enforced procedures of destruction in case of permit contraventions. Liabilities of civil engineers in supervising construction Making technical committees for monitoring of quality and safety procedures
1986	Law No. 2/1986	Leaseholders right to get a new, dissociate tenancy agreement from the proprietor, with the permit of the former leaseholders
1981	Law No. 136/1981	Deluxe condominiums are excluded from rent control
	Article 15	Investors are able to obtain low avail loans supplied by State Agencies, and banks
1980	Law 52/1980	Restricted plot coverage to 60% of the total area, with land division laws assigning 33% of the land for public uses.
1977	Law No. 49/1977	Specified rent as 7% of total cost; permitted foreigners to purchase units, and permit units to be purchased as residential units
	Article 48	Renters right to barter, release, or re-rent their condominiums without proprietor's permit
1976	Law 106/1976	Enjoined building codes for high building standards that grown constructing expenses
1969	Dwelling houses law No. 52/1969	Renters can inherit rental condominiums. Prohibitions of side payments, key money, or advance rent
1964	Dwelling houses Sector Socialization Act	Total transformation from private proprietorship to public proprietorship for the biggest 119 building corporations. united them in 35 public agencies, which also administer the residential real estates socialized in 1961
1962	Law No. 46/1962	Specified rent price as 3% of land price and 5% of building cost

1961	Law No. 168/1961	All rents to be decreased by 20%, for all condominiums, without exception, without appeal
	Nationalization laws	Conversion of the 61 biggest privately possessed real estates, including residential multiplexes, into public property
1954	Dwelling houses Law of 1954	New lowering for all rental condominiums by 20% without exception
	Article 56/1954	Renters right to repine about servicing, which may output in a rent reduction
1952	Military order 129/1952	Rent lowering by 15% for all condominiums established between 1944 and 1952, with no proprietor’s right to defy it
1947	Military order 169/1952	A new tax of 13.7% of all rents, even on condominiums established before 1944
	Law No. 121/1947	blocking rent rates, and concerning rent them to total cost

2.5 Results of Questionnaire Survey

Based on the results of the questionnaire survey, we have classified the responses into three main topics that reflect their opinions on the failures and success of governmental regulations to meet the demand for housing in GCMR from 2001 – 2013 (Table 2.2).

Table 2.2 Questionnaire Responses with Number of Answers for the Main Responses Topics

Results	Main responses topics	No. answers
Failures	Failure of governmental policies to decrease the numbers of Vacant housing units in main core of GCMR	299
	Failure of governmental policies of NUC around GCMR to attract residents instead of slums	213
Successes	Success to increase in the housing investments for public housing	102

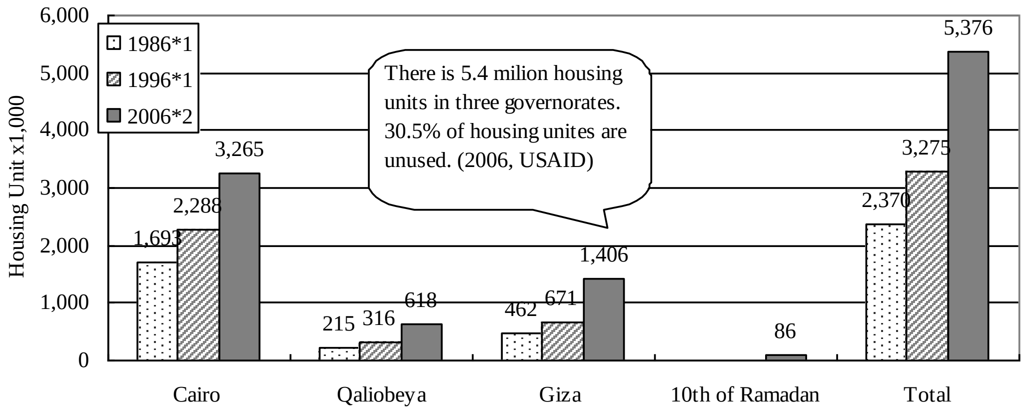


Figure 2.4 Vacant Housing Units in GCMR 1986- 2006

Source:JICA,2008 [8]

2.5.1 Failure of Governmental Policies to Reduce the Numbers of Vacant Housing Units in GCMR

Based on 299 of responses to the questioner, the governmental policies have failed to decrease the number of vacant housing units in GCMR. This opinion was observed in highest number of responses as the most negative aspect of the governmental housing policy between 2001 -2013. Based on figure 2.4, number of vacant housing units have increased from 2.37 million in 1986 to 5.37 in 2006 that reflects the failure of the governmental reformulation of housing rents laws in 1981, and 1996 (Table 2.1). The number of vacant housing units in Cairo governorate jumped from 2.2 million to 3.2 by 43.85 % in 10 years from 1996-2006. In Giza governorate in the western part of GCMR the vacant units increased by 108.9% increasing from 0.67 million to 1.4 million. In Qaliobeya governorate the percentage of increasing was 95.5%.

2.5.2 Failure of NUC around GCMR to attract residents

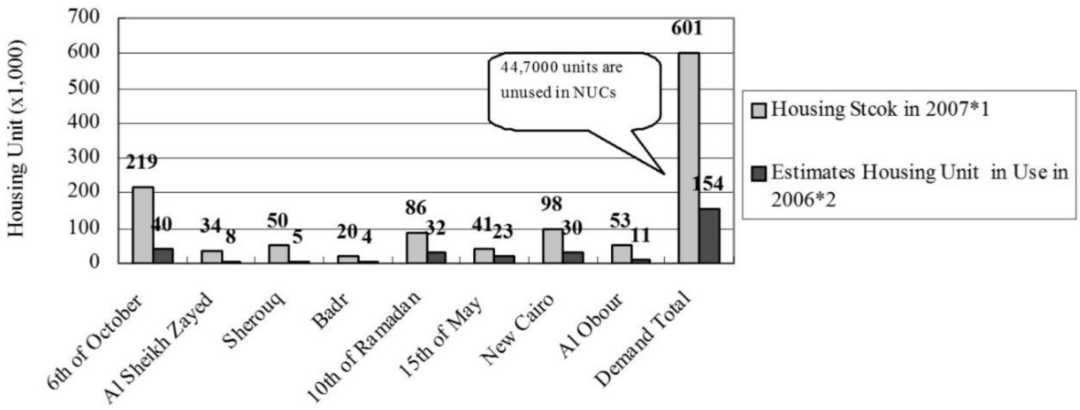


Figure 2.5 Gap between NUC Housing Stock and In Use

Source:JICA,2008 [8]

Based on our questionnaire survey, 213 of respondents mentioned that the governmental housing regulations failed to attract residents from existing GCMR urban core to the NUC (Figure 2.2). Based on figure 2.5, the gap between affordable housing stock and the real housing units in use is 3.9 folds. In all NUC, there are 0.6 million existing housing units. But only 0.14 million units are in use. The highest ratio of gap between the number of housing stock and the units already in use was in Sherouq City with only 10 % of total housing stock is in use. While the city of "15th of May" 59.06 % of the housing stock was in use with less gap ratio that can be considered as the most successful NUC to attract residents. The rest of NUC had similar their ratio of occupation: city of 6th October, 18.2 % of units are in use, Alshiekh Zayed City had 23.52% in use, Badr City had 20 % in use, 10th of Ramadan City had 37.2%, New Cairo city had 30.6%, and Al obour city had 20.7 %.

2.5.3 Success of Housing Policies to Increase the Public Housing Investments

Table 2.3 Official Government Investments in Housing Sector 1982- 2001*

Investments Sectors	1st 5yr Scheme 1982/83 -1986/87		4th 5yr Scheme 1997/98 -2001/02	
	LE million	% of Total	LE million	% of total
Dwelling Houses Sector	492	5.1	2220	12.0
Total Sectors Investments	1306	9.6	9508	22.2

* Source: GOPP,2010 [2]

Table 2.4 Housing Units Established by the Governmental Authorities Budgets 1982-2005*

Governmental Authorities	Housing Units
Ministry of housing construction companies	553,776
New Urban Community Authority	251,061
Dwelling houses and Development corporations	43,118
Joint Projects Agency	17,652
Dwelling houses and building cooperatives	278,277
Dwelling houses Finance Fund	22,168
Dwelling houses and Development Bank	63,674
Development Agency	28,347
Total	1,258,073

* Source: CAPMAS,2006 [9]

Based on Table 2.2, 102 of respondents in GCMR mentioned that the only success of the governmental policies after the 2001 was, increasing the governmental budget allocating for constructing public housing, which is mainly for low and middle class income peoples. Table 2.5 shows the increase of 5.1% -12.0% in total housing budget allocated by the ministry of housing and utilities between 1986 -2001. The allocation of 2,220 million Egyptian pounds which is equal to 450 million US$ was used to build public housing in the existing urban core of GCMR. Based on table 2.4, the governmental has add 1.25 million housing units between 1982 -2005, in which 20 % of them in NUC.

2.6 Analysis and Discussion

The issue of housing access was visible among young families. New home-seekers of low-class incomes are challenged by two dilemmas; firstly, shortage of rent-controlled living quarters within GCMR 's internal condominiums even though some condominiums indeed not occupied; secondly, they cannot pay for the inflated rates of newly established formal dwelling houses in modern condominiums and towns.

As they are eliminated from the formal dwelling house market, there are no alternatives for young peoples, other than houses in the informal sector. Consequently, they settle in informal areas in outskirt of the metropolitan areas. In spite of the urgent necessity for low-cost dwelling house supplies for peoples those have restricted incomes, the general state policy targeted to establish high class dwelling house building. This dilemma has a strong relation with the cumulative governmental regulations during last 70 years but the aspects of this issue become serious starting 2001which we are focused on our survey questionnaire. We observed three main effective points of these regulations, which become effective on the GCMR housing market between 2001-2013. And we connect them with the housing laws 1941-2001 to discover the real origins of the housing issues in GCMR recently.

2.6.1 The Failure of governmental policies to decrease the numbers of vacant housing units in GCMR are related to several cumulative historical reasons:

In 1981 the government clarified the housing Law of 1981 whereby one-third of all housing units within each residential building would be contribute for sale. This law stated that all residential building investors could obtain low interest loans [19]. Later dwelling houses law No. 2/1986 gave leaseholders the right to get a new, dissociate tenancy agreement from the proprietor. According to Makary, 2002 [5], the 1980s building boom represented a contributing role in Cairo's dwelling houses market's recession. High returns on capitals from upper-revenue units during the 1980s have catalyzed a surplus of top-end buildings, outputting in a shortage of housing in the lower end of the market. An unwillingness of property proprietors to rent, because of rigorous rent control laws and speculative inclinations, left 50,000 units vacant in Cairo alone [14]. This effectively restricted the lower to middle- income households from the real estate rental market.

Over the 1980s, the demand for dwelling houses far overridden supply, as government's own building projects couldn't sustain with population growth. The today's relaxed market is related to the decisions of in the early 1990s, when the government permitted private sector corporations to invest tremendously in the real estate business to fulfill housing demand. The private corporations were particularly served rising mobile population whose housing needs would not be satisfied by state housing and development corporations. This condition drove to high vacancy rates of condominiums over Cairo. In comparing with the 2.4million housing units that are being established between 1981 and 1994, the share of the public sector was indeed restricted to 120,000 units [11, 14, and 19].

1990s fundamental modification policies and economic reformation at macro level have worsened the housing problem for lower and middle class of the community, as most public housing investment was specified for supplying of housing units which were unaffordable to the larger number of the residents. The sustained grows in land speculation within and around urban centers created increasing prices, leaving low and middle income urban dwellers with no affordable alternative to the informal housing market. With the fixed low rents problem continued to the next generation of leaseholders. So, proprietors preserved condominiums vacant, or desired high 'key money' payments, which most families could not pay. Finally after the removal of this long-established rent fixing and the 2001 Mortgage law more complex multiple driving forces were observed. Many vacant units were identified in private housing projects with prices affordable to youth in NUC. So, the visible housing shortage and vacancy rates are not only featured to the incompatibility of households and housing units. It is occurring due to the unaffordability of new housing, and inappropriate state housing policies.

2.6.2 The failure of governmental policies to attract residents to NUC instead of slums around GCMR

We, found this failure is related to a problems of housing policies introduced in1970s, 1980s, and 1990s targeted to help poorer people to obtain housing in NUC. NUC dwelling houses projects and other public housing projects have allocated condominiums to low and middle-income people have worsened the housing issue. Some of these new residents returned to their former internal Cairo condominiums while continue hold of their new houses in NUC. Other families cannot pay for rent or mortgage payments or unhappily with the distance to city center or desert surroundings of the New Urban community and left their assigned dwelling, which then become hard to re-let. NUC specially could not attract residents from Cairo centers. Sub-standard services and shortage of social and educational infrastructure have also frustrated families from living in NUC.

A large ratio of the industrial employees in the NUC of 10th Ramadan has daily travel to work from Cairo, as employers were compelled to establish a bus and mini bus system to pick up employees from Cairo and its outskirts [23]. Residents favored to stay existing core of GCMR rather than move to remote cities. As new town houses proved to be too costly for employees, it finally attracted speculators rather than residents, as in Sheikh Zayed Town. By early 1990s the state had renounced the management of some of these NUC to private sector contractors who established villa complexes, and gated communities [10]. NUC did not attain the self-sufficiency goal of the original scheme according to which the new condominiums would contain 2 million people by year 2020 or 150,000– 200,000 people each. To create a more unified urban network, these NUC are integrated in eastern and western development corridors targeting to improve transportation correlations and to attract population growth away from GCMR core [2, 14, and 23].

2.6.3 The success of the governmental housing policies to meet the housing dilemma in GCMR in attracting more housing investments for low-cost public housing.

The successes of the governmental regulations to increase investments for housing market are not only representing the allocated governmental budget but also the private sector investments. The formulating of The Real estate investments law (148/2001) – better known as the Mortgage the General Authority for Real property Finance (GAREF), was prepared to provide long-term loans for purchasing, building and renewing real property at up to 90% of the price of the housing unit. The new mortgage law resists the widespread pro-renter culture, permitting banks to reclaim real estates and deport proprietors who default. Mortgage loans provide up to 90% of the price of the asset, with monthly pay at nearly 40% of the debtor's net monthly revenue, with repayment duration from 25 to 30 years [1, 14]. Increase in premiums for real estate is not new in Egypt.

Recently, building contractors in outskirts on the suburbs of eastern Cairo have set offer affordable payment plans, with low interest rates. According to real estate analysts, some 80–90% of new homes today are bought in premiums, as building contractors, assiduous to put on sale vacant units to alternative finance methods [5, 11]. After the Law No148/2001, more than 300 private sector corporations gained rights to build 450,000 units on nearly 30,000 acres of land in NUC around GCMR. Building contractors have given the public the impression of surplus, making banks resistant to finance new projects and leading customers to delay purchasing in the hope that prices will collapse [19].

2.7 Conclusion

This paper introduced results that are important for urban planners and housing decision makers in GCMR and in developing countries. In order to meet housing demand, they have to prepare an integrated housing plan parallel process to manage both of urban issues and governmental budget.

Governmental budget has to focus specific areas such as; supporting amenities, public transportation modes and infrastructure, which can be more effective in meeting the urban housing demand. Working teams of the governmental housing authorities indicated that failure to meet housing issue although the housing budget was increasing throughout the period. The problem in GCMR is not in number of housing units but it is in the failure to serve the requirements of living necessities such as infrastructure, amenities, and public transportation for NUC which had less than 26 % of units are in use.

The failure to encourage the owners of 5.4 million vacant housing units inside the existing urban core of GCMR increased the housing problem. We can say that, GCMR does not have problem in housing units but the problem is in how can we manage the existing housing stock and make them in use. Government needs to allocate its budget to support NUC by life facilities and work chances. On the other hand, the absence of integrated regulations encourages the housing speculation by increasing demand, and the greater accessibility of mortgages. Speculative house building by high and middle class residential condominiums generated in easily noticeable amount of vacant condominiums. We can say that housing market is increasingly supported by property speculation of the middle class. There is a necessity for better regulation furthermore better supplying of hosing for poorer families with regulative controls to restrict its filtering to middle-income families and to speculators.

The future researches in this area have to prepare a decision support system that can make the required integration system among financial, technical, political, and consumers in the housing market in GCMR and be connected with fieldwork. To meet the real need of consumers and transfer it directly to political and financial authorities to allocate money based on their real needs not only based on blind numbers of housing demand from technical analysis.

References

[1] El Araby, M M (2002). Urban growth and environmental Degradation; the case of Cairo, Egypt. Cities 19 (6), 389–400.

[2] GOPP (2010). Cairo Future Vision 2050: Within a National Vision of Egypt. Ministry of Housing, Utilities and Urban Development. Cairo, Egypt.

[3] Zurayk, H and Shorter, F (1988).The Social Composition of Households in Arab Cities and Settlements: Cairo, Beirut, Amman. Population Council, Regional Papers: West Asia and North Africa, August 1988.

[4] Ibrahim, Fouad N and Ibrahim, Barbara (2003). Egypt: An Economic Geography. I.B. Tauris, London, New York.

[5] Makary, S (2002).The Real Estate Sector in Egypt. American University in Cairo Press, Cairo.

[6] Sejourne, M. (2006). Les politiques recentes de 'traitement' des quartiers illegaux au Caire : nouveaux enjeux et configuration du systeme d'acteurs? Ph.D. Thesis, University F. Rabelais. Tours, France.

[7] Sims, D., M. Sejoume and M. El Shorbagi (2003). Urban Slums Reports: The Case of Cairo, Egypt (Case Studies for the Global Report on Human Settlements (2003): German Technical Cooperation (GTZ). Cairo, Egypt.

[8] JICA (2008). The strategic urban development master plan study for sustainable development of the Greater Cairo region in the Arab Republic of Egypt. The final report summary, volume 1. Cairo, Egypt.

[9] 9 .CAPMAS (2006).General Census of Population, Housing and Buildings 2006. Central Agency for Population, Mobilization and Statistics, Cairo.

[10] Denis, (1997). Urban planning and growth in Cairo, Middle East Report, 27 (1) (1997), pp. 7–12.

[11] El-Kadi, Galila (1987).L'Urbanisation spontane´e au Caire. Fascicule de Recherches No. 18, ORSTOM/URBAMA, Tours.

[12] Singerman, (1995).Avenues of Participation. Family Politics and Networks in Urban Quarters of Cairo, Princeton University Press, Princeton, NJ (1995).

[13] Shorter, F (1989). Cairo's Leap Forward: People, Households and Dwelling Space. American University in Cairo Press, Cairo.

[14] Sutton and Fahmi, (2001). Cairo's urban growth and strategic master plans in the light of Egypt's

1996 population census results Cities, 18 (3) (2001), pp. 135–149.
[15] Harris, Richard and Wahba, Malak (2002). The urban geography of low income housing: Cairo (1947–96) exemplifies model. International Journal of Urban and Regional Research 26 (1), 58–79.
[16] Creswell JW & Plano Clark VL (2007). Designing and conducting mixed methods research. Thousand Oaks, CA: Sage.
[17] Taylor, I. (2012). Survey sample sizes e How many respondents do you really need?. Last ac-cessed 04/26 2012 at http://blog. questionpro.com/author/thirdforce/.
[18] Hanna, (1992). Le logement en Egypte: essai critique CEDEJ, Le Caire (1992).
[19] M.M. El Araby (2003). The role of the state in managing urban land supply and prices in Egypt Habitat International, 27 (2003), pp. 429–458.
[20] Malpezzi, (1998). Welfare analysis of rent control with side payment: a natural experiment in Cairo –Egypt Regional Science and Urban Economics, 28 (1998).
[21] El-Batran and Arandel, (1998). A shelter of their own: informal settlement expansion in Greater Cairo and government Responses Environment and Urbanization, 10 (1) (1998), pp. 217–232.
[22] Kardash, H (1992).The balance between government and users involvement in housing provision in Egypt. In Proceedings of the Housing International Conference: Policies and Housing Systems for Low-income Communities. Ministry of Development, New Communities Housing and Public Utilities, Cairo (pp. 74–86).
[23] Stewart, (1996). Cities in the desert: the Egyptian new town program, Annals of the Association of American Geographers, 86 (3) (1996), pp. 460–479.

3. Spatial indices to quantify and analyze the spatial-temporal urban sprawl patterns

∗ This chapter is based on the following paper:

Osman, T., Arima, T. & Divigalpitiya, P., 2016. Measuring Urban Sprawl Patterns in Greater Cairo Metropolitan Region. J Indian Soc Remote Sens, 44(2), pp.287–295. Available at: http://dx.doi.org/10.1007/s12524-015-0489-6.

Abstract

On the subject of urban sprawl in recent Egypt, this research takes Giza governorate the western part of Greater Cairo Metropolitan Region (GCMR) as a case and puts forward that urban sprawl can be estimated from spatial disposition, sprawl efficacy and outer influences; and then evolves a geo-spatial indicators system for quantifying sprawl. Various data sources were selected, including land use maps, digitized map of the highways and town centers, and population statistical data, etc. The results demonstrated that Building land in Cairo has kept quick growing with considerable amount of low efficacy and dysfunctional spatial disposition.

Keywords: *Urban Sprawl, Growth Efficiency, Sprawl measurements, Remote Sensing, Egypt*

3.1 Introduction

Notwithstanding the government's attempt to contain it Egypt has experienced a rapid urbanization over the past five decades. Official Governmental efforts started in 1956 with the introduction of first urban development plan for Greater Cairo Metropolitan Region (GCMR). Later it was followed by new plans in 1973, 1982, 1991, and 2006 [1]. The population of GCMR was around 16-18 million inhabitants, which corresponds to nearly a quarter of Egypt's population of 72,798 million inhabitants in 2006 and about half of the country's urban population. [1] The labor force is growing at over 3.0 % per year, due to the considerable youth lump in the population pyramid [1].

In GCMR more than 7 million inhabitants live in informal areas; 80 % are on privately owned arable lands [2, 3]. Urban sprawl in GCMR is mainly classified into two classes: (1) Urban sprawl on previous arable lands over and (2) urban sprawl on previous State land [4]. The Urban sprawl areas have expanded particularly on private arable lands, and less frequently on publicly owned desert land. Based on the UNDP, 2004 [2], by 2025, around 50% of Egypt's urban population is anticipated to dwell in Urban sprawled areas. Cairo is located on the Nile valley where the Nile's flow is calm and with desert hills both to the desert (Figure 3.1) Historic Cairo (i.e. pre-1860) was limited the higher ground near to the eastern hills. GCMR is consisting of the entire of Cairo Governorate and the urban areas of Giza governorate (west of the Nile) and Qaliubia Governorate (north of Cairo Governorate). Governorates are the major areas of municipal administration in Egypt. Cairo is not only the Political capital of Egypt but also its service, social, economic, and administrative hub.

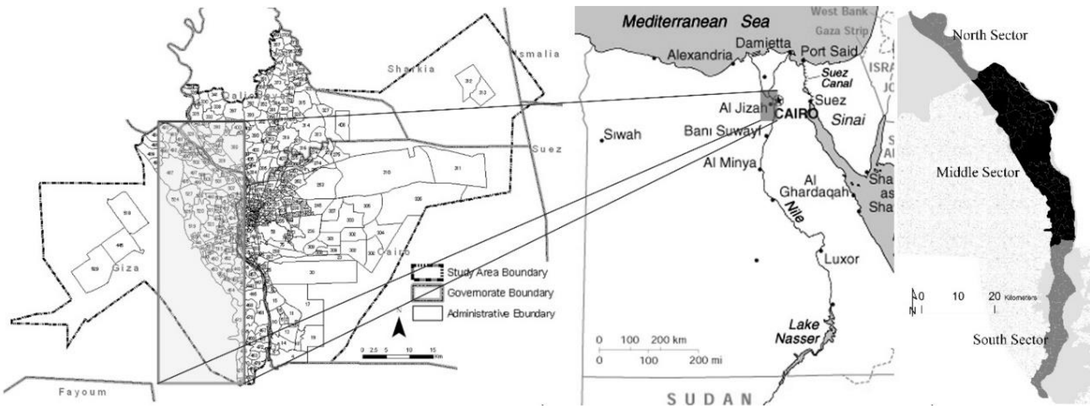


Figure 3.1 Study Sectors Location within Egypt

Source:JICA,2008 [1]

Table 3.1 Urban and Population Growth in Giza Sectors (Middle, North, South) 1984,2004, and 2013

Study	1984		2004		2013	
Sector	Urban (ha)	Population No.	Urban (ha)	Population No.	Urban (ha)	Population No.
North	187,37	51240	588,26	95323	891,10	111814
Middle	8354,80	1807909	12962,04	3363552	18470,98	3945166
South	861,70	237512	1770,80	441883	2773,10	518292

A research using satellite images estimated that the surface area was covered by urban sprawl in GCMR between 1991 -1998 has grown by 3.4 % per year, while the population living in the urban sprawl areas grew by 3.2 % per year [5]. MOP & GTZ,2004 [6] mentioned that erosion of arable lands, since 1980, is estimated at about 1 million Acres which represents around 12% of total agricultural land in Egypt. This coincides to an annual lack of 0.6% of Egypt's total arable lands .El-Hefnawi, 2005 [7] mentioned that estimated amount of all arable lands property categorized to urban sprawl areas is US $ 46.2 billion, in addition to informal areas which are US $ 16.9 billion, and also US $ 63.1 billion as cost for informal buildings over arable land with total number of 7.9 million informal units. SIMS, 2003 [8], UNDP, 2004 [2], MOP&GTZ ,2004 [6] mentioned that urban sprawl in the past decade was quite serious, and the tendency of scattered development and sprawling growth will hinder the Egyptian development process if the urbanization could not be kept under control. Lately, the unfavorable influences of urban sprawl have got more visible, and the concerned government has started to search solutions for urban sprawl.

Knowledge of the Spatio-temporal pattern of urban sprawl is important to understand the size and functional changes of the urban sprawl. Spatial metrics were computed to quantify the patterns of urban dynamics that aid in understanding spatial patterns of various land cover features in the region [9]. Quantifying the urban sprawl patterns and its change is essential for monitoring and assessing the urbanization process and its ecological consequences [10-13]. Spatial metrics have been widely used to study the structure, dynamic pattern with the underlying social, economic and political processes of urbanization [14-17]. This has provided useful information for implementing holistic approaches in the regional land-use planning [18]. Aguilera& Talavera, 2009 [19] Reviews the spatial characteristics of metropolitan growth including analysis [20-23] the study of urban sprawl.

Applications of urban sprawl metrics include urban sprawl spatial disposition (area index, shape index, discontinuous development, strip development, and leapfrog development index), geographical applications by taking advantage of the properties of these metrics [24-26] and measurement of ecological sustainability [3]. These studies also confirmed that Spatiotemporal data along with urban sprawl metrics would help in understanding and evaluating the spatio-temporal patterns of urban sprawl dynamics required for appropriate management measures. According to the GCMR Development Plan, a 20-year vision document for Giza governorate as a part of GCMR, there has been a 44.47 % increase in the Regions spatial extent in the period 2004-2013, resulting in the higher degree of sprawl at outskirts.

All in all, we applied Giza governorate as a case study in this paper to understand the urban sprawl dynamics in the context of metropolitan region of the developing countries. This study aims to quantify the changings of Giza urban sprawl dynamics through the selected spatial indices which aiming ultimately to help the decision-makers in GCMR on adjusting the urban sprawl.

3.2 Identifying Urban Sprawl Indices for Giza Governorate

Recent researches submitted indicators for quantifying sprawl, among which the weightiest ones are submitted by Sierra Club, Smart Growth America. Sierra Club, 1998 [27] classified main metropolitans in USA by four sprawl indicators: time cost on traffic; comparison of land-use and population growth; population moving from inner region to outskirts. USA To-day, 2001 [28] submits the share of population beyond as an indicator for quantifying sprawl. They implemented a research to find the influences of sprawl on life goodness in which four indicators were used to quantify urban sprawl: vitalization of inner region; hodgepodge of residence, residential density; service facilities and accessibility of transportation network.

In developing countries, researchers used repeated indices to quantify the urban sprawl. These indices are usually known as spatial indices. Spatial indices are numeric measurements that quantify spatial patterning of land-cover patches, entire landscape mosaics of a geographic area, or land-cover categories [9]. Some papers have participated to quantify sprawl by setting up multi-indicators by GIS analysis or explanatory statistical analysis [29-31]. These indicators cover various features including traffic, resources consumption, employment, population, living goodness, architecture aesthetics. Common used indicators: spatial disposition like proximity, accessibility, fragmentation or; residential density, population density, employment density; growth rate like built-up area growth rate, population growth rate; and others like land-use efficacy, per-capita land consumption [32-35]. The start of research in multidimensional indices of urban sprawl was established by Galster et al., 2001 [36]. They classified land use patterns into eight dimensions: nuclearity, clustering, centrality, density, heterogeneity, proximity, concentration, and continuity.

Cutsinger et al., 2005 [37] improved the multidimensional indices measures by using a dozen conceptually featured dimensions of land use patterns which were operationalized for

50 considerable US metropolitan areas. Under the name of sprawl indices, Angel et al., 2007 [38] have submitted five indices for quantifying manifestations of sprawl and five groups of indices for quantifying the sprawl. Under each group they have used diversified indices to quantify the urban sprawl case studies. But, they have not endorsed any standard sill that can be used for identifying a sprawling region from a non-sprawling region.

In addition to that, in China as a developing country Jiang et al., 2007 [26] suggested a dozen of 'geospatial indicators'for quantifying the urban sprawl. They suggested an incorporated sprawl index that consolidates 13 indicators. This concept decreases the explanation effort. But their concept needs immense inputs of temporal data like GDP, floor-area ratio, land-use maps, land-use master planning, maps of region centers, maps of highways, and population. Since, developing countries denies rare of such type of temporal data; most of these indicators are laborious to get. Furthermore, they did not indicate to any sill to classify a region as sprawling or non-sprawling. Nevertheless, this type of temporal analysis is serviceable to differentiate among regions or various zones of a region at various dates. Whether a region is being more sprawling or not, with the alteration of time, can be well described by this pattern of analysis.

All in all, most of the international researches took the entire region as an analysis unit to estimate these indicators, which could strictly differentiate the sprawling situation of the region, but the inner differentia of sprawl in a given region could not be well described. Furthermore, some indicators are submitted based on the context of Western urbanization; therefore, they are not so appropriate for quantifying sprawl in Giza governorate, such as the share of detached house. In addition, some necessary statistic data are not sequent enough to estimate certain indicator, such as the density of employment.

In developing Countries, some indicators were developed for quantifying urban sprawl which could be used for reference in Giza case study. Those indicators include: Growth scale, such as urban sprawl area [39]; growth speed, such as annual growth rate [40]; landscape disposition, such as isolation index, shape index, fractural dimension [41]; and spatial attributes such as built-up area, annual growth density [42]. The last three types of indicators are appropriate for quantifying widespread cases of sprawl, but not convenient in identifying inner differentia. The annual growth density and built-up area density could successfully characterize the sprawl attributes of strong change and low density, but they are until now feeble in identifying the particular spatial patterns of urban sprawl.

To summarize, the common international sprawl indicators could not be clearly used in the GCMR context. No existent indicators on urban sprawl in the Egyptian context could be clearly used to quantify the urban sprawl either. So, this paper submits a combination of geo-spatial indicators for quantifying sprawl based on the special case of Giza governorate the western part of GCMR in Egypt.

We define Urban sprawl in GCMR as an ascendancy of low density urban areas structures with mutation of previously monocentric compact region into polycentric, discontinuous, spontaneous urban pattern de-concentration of urban functions in incorporation with urban sprawl into rural communities in addition to that it witnessed dissident development conflicting to purposes of spatial planning concepts and ideas; and Pertinent impacts on the urban community by the neoteric spatial pattern, like traffic flood. Consequently, the analysis of the urban sprawl phenomenon must be accentuated from this multidimensional perspective.

Based on the previous working definition, ten of geo-spatial indicators have been determined: spatial disposition, growth efficacy, and outer influences to quantify sprawl in Giza. These measure included, five indicators such as size and shape of land use patches which espoused to identify the spatial disposition of Giza's urban sprawl. Two indicators included horizontal building density and population density were used to dissect the efficacy of urban sprawl. Another three indicators included arable land erosion, open space erosion, and traffic encumbrance are submitted to specify the influences on environment, agriculture, and region life. Due to the rare of statistic data, the description of spatial differentia of economic output is not appropriate yet in addition to other influences of urban sprawl, such as energy consumption, which are not included in the indicators system due to data scarce.

3.3 Methods and Data

3.3.1 Research Study Sectors of Giza Governorate

Administration hierarchy Egyptian municipalities follow an old centralized system introduced 1960s when country become a socialist state. Municipality services and information such as; municipal budgets, transportation networks, census data, etc. are organized based on that hierarchy. We have followed this hierarchy and divided the main study area of Giza governorate sector in to three sub-sectors for this study (Figure 3.1).

3.3.2 Data sources

Data included population at local administrative level of GCMR collected from the national census in 2006 [5], land use maps in 2005 from GOPP land use surveys, the existing GCMR land-use master planning (2007–2027), and vector maps of highways and local municipalities centers digitized from the hardcopy of Giza geographical base map. Method for computing indicators are as followed: 1) data elaboration by which to procedure various data to set up workable database for each index; 2) adapt all indices by spatial analysis to consolidate all of them into the same grid platform of 120m×120m; 3) Calibration conversion by which to normalize these indicators with diverse dimensions; and 4) AHP was applied to make ranking and weighting [43] for the applied various urban sprawl indices, and then sum up all calibrated indicators into one integrated sprawl index (ISI). The formula is given: ISI= 0.02 AI + 0.03 Si + 0.21 DDI + 0.23 SDI + 0.13 LDI+ 0.06 HDI + 0.07 PDI+ 0.10 AII+ 0.04 OSII+ 0.10 TII. Where ISI stands for the integrated urban sprawl index, each sum term stands for one of 10 indicators respectively; operator reflects the correlation with urban sprawl. We used the equal interval method to classify the indices calculation output to categories.

3.4 Results and Discussion

As for finding solutions to the negative impacts of urban sprawl in Giza, the first step is to understand the sprawl attributes in precise indices. However, the previous researches tried to understand the urban sprawl in such cases of GCMR in developing countries still concentrated on specific debate instead of quantitative analysis. Previous researches had no obvious answer on how to differentiate sprawl, estimate the extent of sprawl or estimate the policy impact. The existing methods for quantifying urban sprawl are fundamentally submitted within the context of Western advanced countries. So those methods are not precisely developed for understanding the spatial attributes and unique mechanism of urban sprawl within the context of metropolitan region in developing countries like GCMR.

In this paper, the following results founded that buildable-arable lands in Giza have kept a rapid expansion with a huge amount of low effectiveness and dysfunctional spatial distribution. The subsequent definite sprawl attributes are determined; conspicuous fragmentation and unevenness of landscape due to ineffective implementation of land use planning; inappropriate pattern of land use growth with exemplary discontinuous development, strip development and leapfrog development; low density of land use growth, low population density and economic output in the NDL; and other unfavorable influences on agriculture, environment and region life.

(1) The conspicuous fragmentation of new urban sprawl areas could be identified by AREA INDEX which shows land use patches had conspicuous fragmentation tendency. From 2004- 2013, the patch number of non-arable lands grew by 19.3%; over the average patch size grew by 69.4%.The average patch size of the newly developed land (NDL) is 5.47 km2, and 100% of them are more than 1 km2 (Figure 3.2). As Shape index shows, land use patches became more irregular forms. The average shape index of the NDL patch is 0.24, and the shape index is comparatively massive, ranging from 0.001to 127.06. Only 3.6 % of them are over 0.24 (Figure

3.3). As Discontinuous development index shows, 76.9 % of the NDL is neighboring to the previously developed lands (less than 100 m). The average range between the NDL to the previously developed lands is 76 m (Figure 3.4). As SDI demonstrates, the NDL has an exemplary feature of strip development, particularly urban land. The average distance between the urban NDL and highways is 388.9 m, and nearly 91.66% of the urban NDL is situated in the 1-km buffer of the highways (Figure 3.5). As LDI demonstrates, the NDL has a typical feature of leapfrog development. The average distance between the NDL and county centers is about 149.4 m, and 71.11% of the NDL has a distance less1 km to county centers (Figure 3.6).

Table 3.2 Quantifying Spatial disposition of Urban Sprawl

Index	Calculation methods	Data source
AREA INDEX (AI)	AI= patch area of newly developed;	Land use maps 2004-2013
SHAPE INDEX (SI)	SI= 0.25×Perimeter/ (area) [44]	Land use maps 2004-2013
DISCONT. DEVELOP. (DDI)	DDI=distance between newly developed and previously developed land	Land use maps 2004-2013
STRIP. DEVELOP. INDEX (SDI)	SDI=distance between newly developed patches and high-ways	Land use maps; map of Major roads 2004-2013
LEAPFROG DEVELOP. INDEX (LDI)	LDI=distance between newly developed patches and county centers	Land use maps; map of centers (point) 2004-2013

Table 3.3 Quantifying Growth Efficacy of Urban Sprawl

Index	Calculation methods	Data source
HORIZONTAL DENSITY INDEX (HDI)	HDI=The share of non-arable lands area within neighborhood of 1 km2	Land use maps 2004-2013
POPULATION DENSITY INDEX (PDI)	PDI=ratio of population to land area	Population at village level; land use map in 2004-2013

Table 3.4 Quantifying Outer influences of Urban Sprawl

Index	Calculation methods	Data source
AGRI. IMPACT (AII)	Overlay analysis; AII={1, 0}, 1 stands for arable land loss	Land use maps 2004-2013
O.SPACE IMPACT (OII)	Overlay analysis; OII={1, 0}, 1 stands for open space loss	Land use maps 2004-2013
TRAFFIC IMPACT (TII)	TII=simulated Population × distance to urban units centers	map of centers (polygon) 2004-2013

(2) Low efficiency of the urban sprawl which occurred 2004-2013 in Giza can be identified from HDI index, the horizontal density of the NDL is more than before. The average density of

the NDL from 2004 to 2013 is 0.24, while the average density in 2004 is 0.15(Figure 3.7). Moreover, there is distinct spatial difference. For example, the density in urban areas situated in the North and south sectors is 0.16 which is 50% of that in the Middle sector (0.30) or 20% of that in the CBD (0.80) (Figure 3.8).

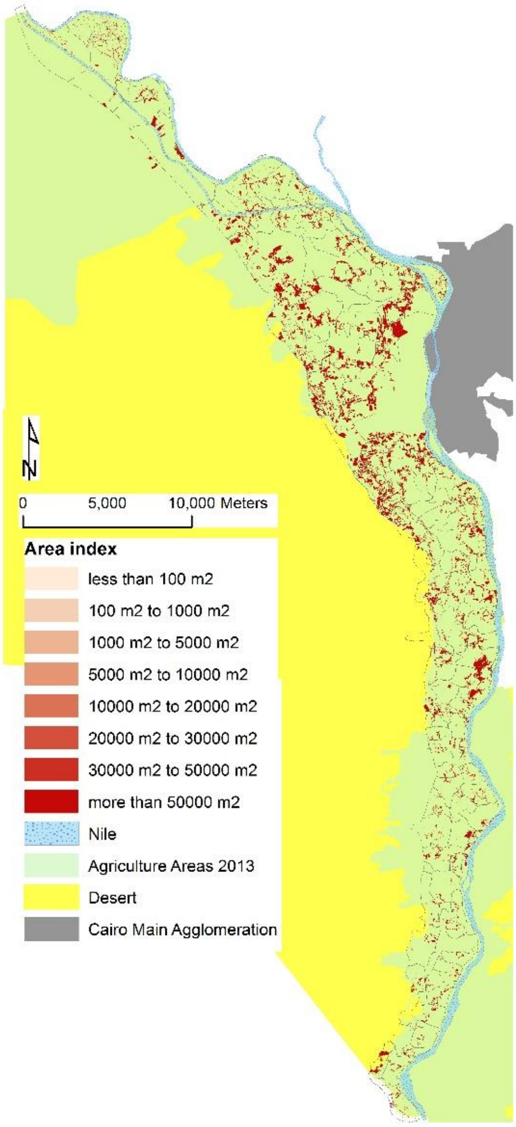


Figure 3.2 Area Index

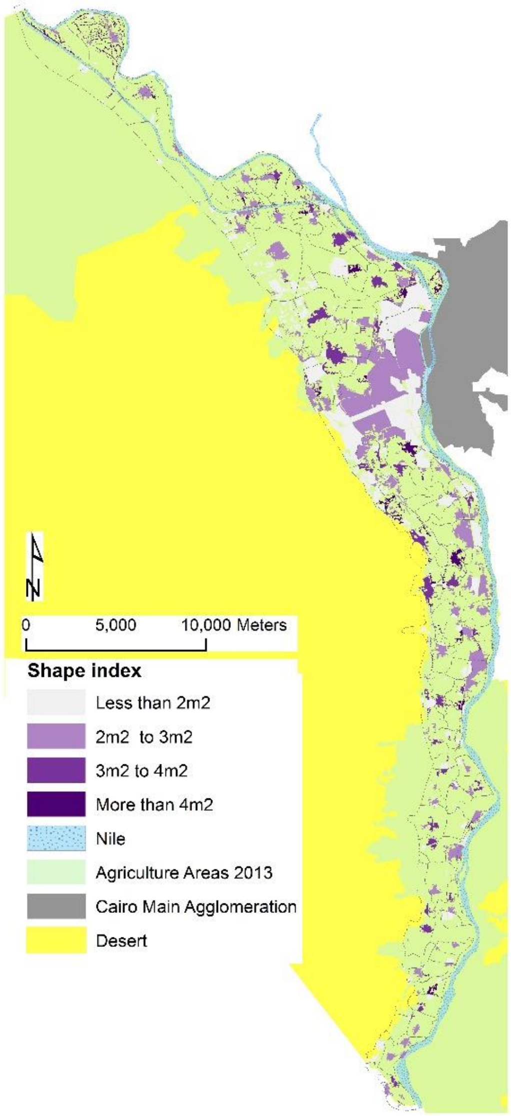


Figure 3.3 Shape Index

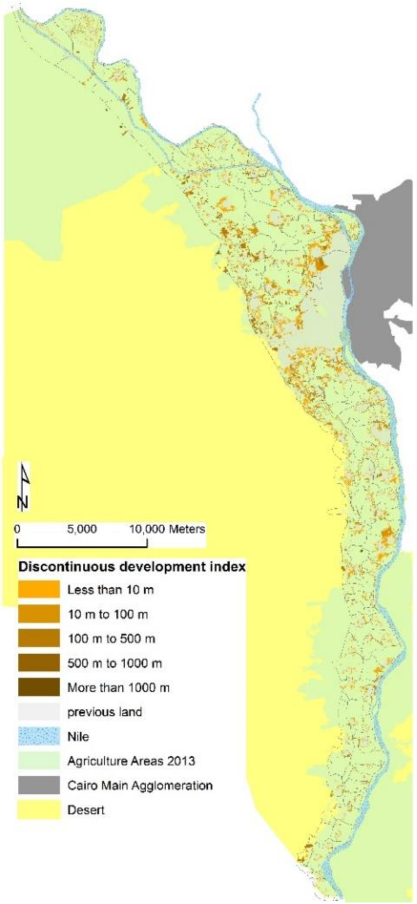


Figure 3.4 Discontinuous develop. index

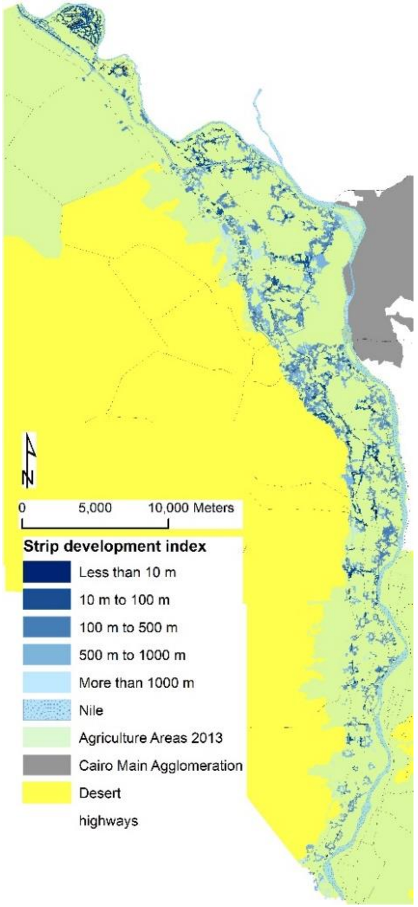


Figure 3.5 Strip develop. Index

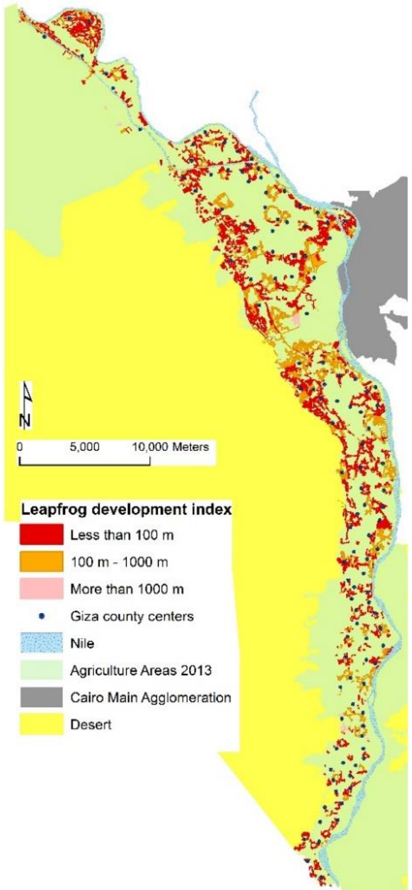


Figure 3.6 Leapfrog develop. Index

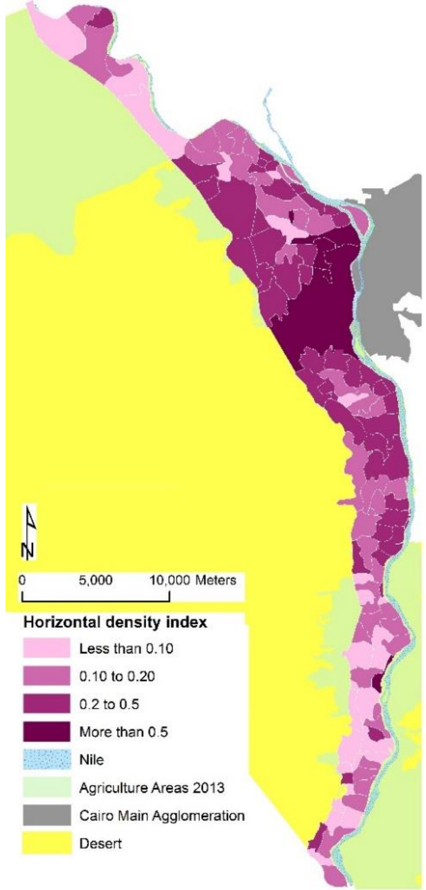


Figure 3.7 Horizontal density index

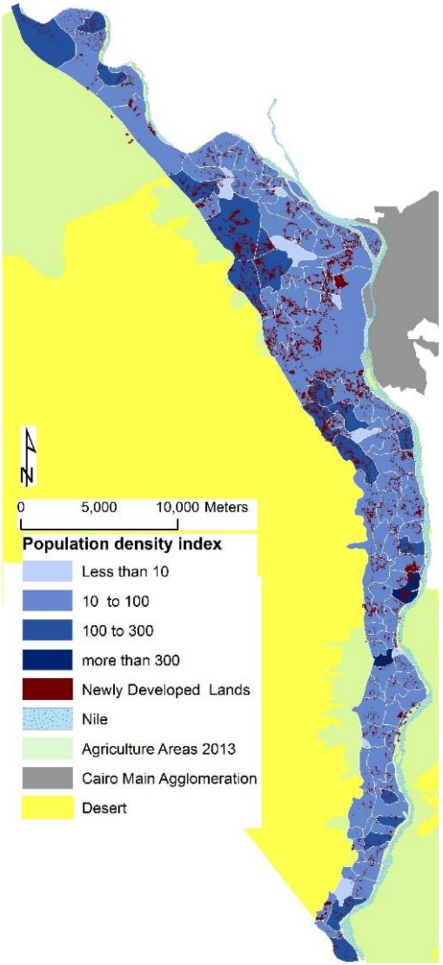


Figure 3.8 Population density index

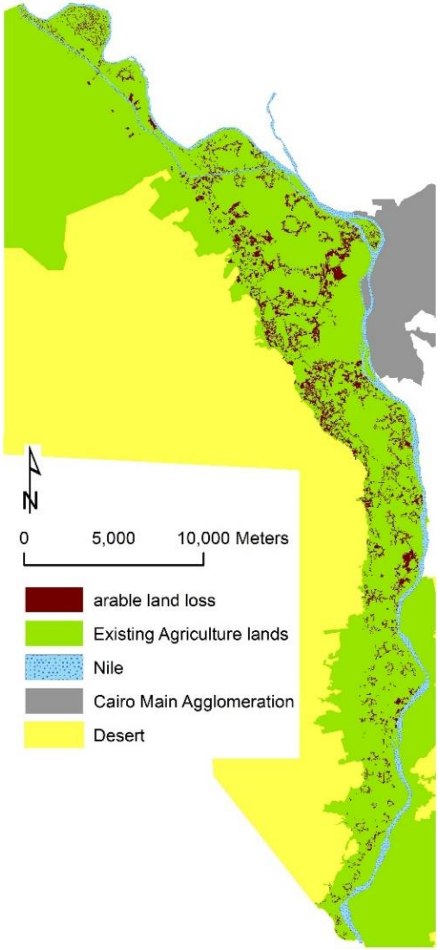


Figure 3.9 Agriculture impact index

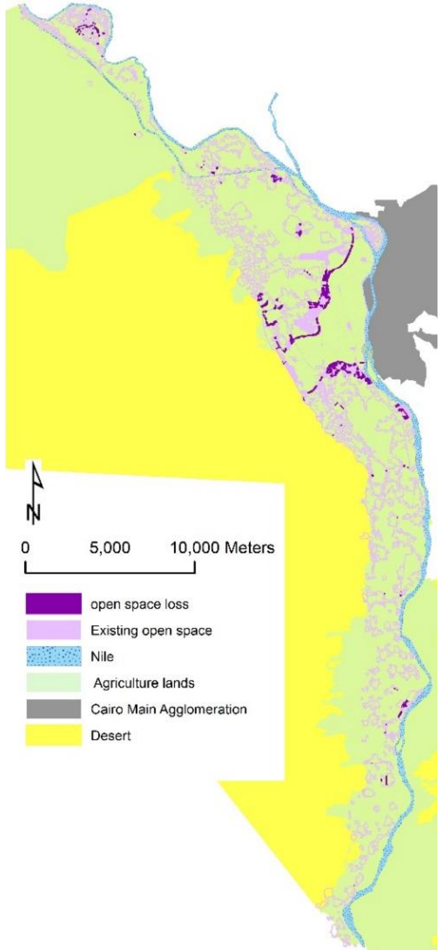


Figure 3.10 Open space impact index

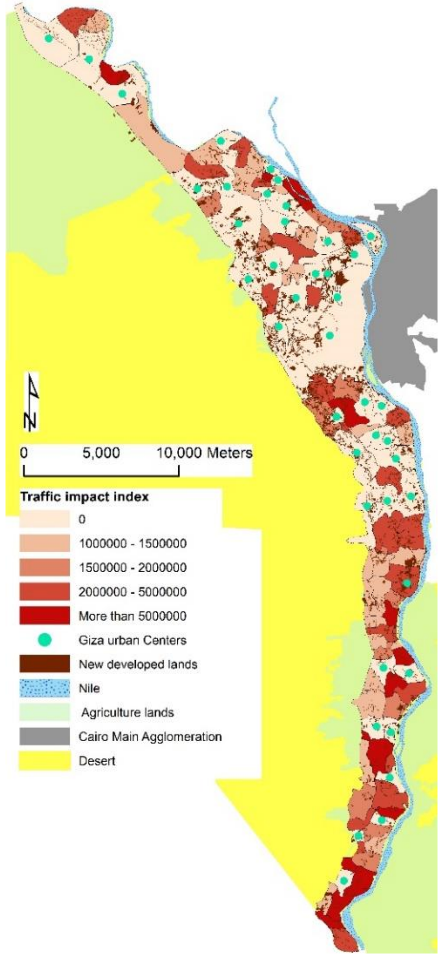


Figure 3.11 Traffic impact index

(3) Negative impacts on agriculture lands, environment and region life can be observed from the indices values of AII, OII and TII. Firstly, urban sprawl has led to enormous loss of high quality arable lands in the region`s outskirts. 74.7 km2 of the NDL were converted from arable land to informal urban areas from 2004 to 2013 (Figure 3.9). Secondly, urban sprawl has restricted open spaces, such as water bodies; 5.33 km2 of the NDL were Converted from open space from 2004 to 2013 (Figure 3.10). Thirdly, the urban sprawl led to inconsiderable traffic onus and expanded the distance between the NDL and main urban core of Giza governorate (Figure 3.11).

(4) Interior differentia of urban sprawl in Giza governorate was identified from the less rate of sprawling in the middle sector in comparison with the serious high rates of sprawling at the North and south sectors particularly in the area near major roads and surround county centers. Four examples of sprawling patterns included spontaneous and new spreading urban sprawl at urban fringe in North and south sectors, road influenced pattern along Regional roads, Edge growth development surround main cores of existing urban centers (Figure 3.12).

(5) The integrated sprawl index (ISI) shows that NDL could be categorized into three categories: low, moderate, and high sprawling by natural break method (Figure 3.12). High sprawling scored 19.9% in the north sector, while it was 46% in the south sector, and 25.8% in the middle Sector. Moderate sprawling scored 30.5% in the north sector, 28.1% in south sector, and 24.0% in the middle Sector. Low sprawling scored 49.6% in North, 74.5% in South, and 50.2% in middle sectors. In addition to that, serious sprawling fundamentally located in three spots particularly, in the farthest part of Northern sector around the regional transportation network, middle and southern parts of Central sector near to CBD and surround main urban centers of cities and mother villages.

3.5 Conclusion

Urban expansion has been and will continue to cause one of the biggest human effects on land surface environment. Many cities, particularly in emerging economies, are faced with complicated problems of urban sprawl. Spatial and temporal studies on urban sprawl or urban areas expansion are necessary for land planning and urban planning in Egypt, which is experiencing a rapid increase of land demand for construction in the context of economic development. Understanding the change in the spatial configuration of urban areas over time is essential for quantifying the effects of urban sprawl [45].

The study results of the short-term sprawl revealed a notable expansion of urban areas between 2004 and 2013. The pattern of the urban sprawl types showed a tendency of leading the pattern of the whole landscape composed by the four different sprawl types to become regular in shape and clumped in distribution. The method used in the present study provided an effective way to the traditional empirical observation of urbanization for related studies. This method can be applied to investigate regional urban area expansion, the pattern change of the different urban sprawl types, and the related land effects of regional policy and economy. This method also bears high potential to be replicated or modified in the study on other regions undergoing rapid urban sprawl.

When the GCMR government's focused to develop the outskirts 's of the metropolitan region , has posed a challenge as unplanned developmental activities is leading to urban sprawl impinging basic amenities to the common man in the outskirts. Spatial indices in conjunction with the density gradient approach have been effective in capturing the patterns of urbanization at local levels. The techniques would aid as decision-support tools for unraveling the impacts of classical urban sprawl patterns in GCMR. A set of spatial indices describing the morphology of unplanned areas have been extracted along with temporal land uses. The extracted indices have indicated the areas of high likelihood of "unplannedness" considering the three dimensions (size/density/ pattern). Local urban and rural planners need to put forward effective implementable adaptive plans to improve basic amenities in the sprawl localities. Temporal land use analysis along with urban density gradient across four directions has helped in visualizing the growth along with the cultural and industrial evolution.

Finally, because of the shortage in the existing study to analyse the relation between urban sprawl and ecosystems, the need to find new indices to describe this relation is crucial to understand urban sprawl dynamics in GCMR.

References

[1] JICA (2008). The strategic urban development master plan study for sustainable development of the Greater Cairo region in the Arabic Republic of Egypt .the final report summary, volume 1. Cairo, Egypt.

[2] UNDP/INP. (2004). Egypt human development report 2004: Choosing decentralization for good governance Cairo, UNDP/Institute of National Planning, Egypt.

[3] Taher Osman, Takafumi Arima, Prasanna Divigalpitiya, The Tale of Slums in Cairo Region: Describing the actual gap between the unplanned and planned urban growth in the greater Cairo Metropolitan Region, journal of Habitat engineering and urban design 2014b, Vol 6. No.1,83-93.

[4] Taher Osman, Takafumi Arima, Prasanna Divigalpitiya, Pseudo urbanization in Cairo Region Measuring urban sprawl with geo-spatial indices, Proceedings of IASUR Conference 2014a, Tokyo, Japan.

[5] CAPMAS. (2008). the final results: Population and housing census 2006.

[6] MOP and GTZ, 2004. (Ministry of Planning - German Technical and Financial Cooperation), New Practice of Participatory Local –Development in Egypt's Urban Areas, Policy Paper, Egypt.

[7] El-Hefnawi, A. (2005). Protecting agricultural land from urbanization or managing the conflict between informal urban growth while meeting the demands of the communities. Third urban research symposium on Land Development, Urban Policy and Poverty Reduction. Brasilia, DF, Brazil: World Bank Institute of Applied Economic Research (IPEA).

[8] Sims, D. (2003).The case of Cairo, Egypt UN habitat, global report on human settlements 2003, the challenge of slums, Earthscan, London.
[9] K. McGarigal, B. J. Marks, 1995. "FRAGSTATS: spatial pattern analysis program for quantifying landscape structure." USDA Forest Service General Technical Report PNW-351. www.umass. edu/landeco/research/fragstats/fragstats.html.
[10] M. Herold, J. Scepan, K.C. Clarke, (2002). "The use of remote sensing and landscape metrics to describe structures and changes in urban land uses." Environ. Plann. A 34, pp.1443–1458.
[11] M. Luck, J.G. Wu, (2002). "A gradient analysis of urban landscape pattern: a case study from the Phoenix metropolitan region, Arizona, USA." Landsc. Ecol. 17, pp. 327–339.
[12] M. Pereira dos Santos Silva, G. Camara , M. Sobral I. Escada, R.C. Modesto de Souza, (2008). "Remote sensing image mining: detecting agents of land-use change in tropical forest areas." International Journal of Remote Sensing 29 (16), pp. 4803-4822.
[13] Y. Li, S. Zhao, K. Zhao, P. Xie, J. Fang, (2006). "Land-cover changes in an urban lake watershed in a mega-city, central China." Environmental Monitoring and Assessment, 115, pp. 349-359.
[14] G.D.Jenerette, D. Potere. (2010). "Global analysis and simulation of land-use change associated with urbanization." Landsc. Ecol. 25 (5), pp. 657–670.
[15] G.D. Jenerette, J. Wu, (2001). "Analysis and simulation of land-use change in the Central Arizona – Phoenix region, USA." Landsc. Ecol. 16, pp. 611–626.
[16] Schneider, K.C. Seto, D. Webster, (2005). "Urban growth in Chengdu, Western China: application of remote sensing to assess planning and policy outcomes." Environ. Plann. B 32 (3), pp. 323–345.
[17] X. J. Yu, C.N. Ng, (2007). "Spatial and temporal dynamics of urban sprawl along two urban-rural transects: a case study of Guangzhou, China." Landsc. Urban Plann. 79, pp. 96–109.
[18] T. Simoniello, M.T. Carone, R. Coppola, A. Grippa, M. Lanfredi, M. Liberti, M. Macchiato, (2006). "Preliminary study to monitor land degradation phenomena through landscape metrics. In: 2nd Workshop of the EARSeL SIG on Land Use and Land Cover." Center for Remote Sensing of Land Surfaces, Bonn, pp. 408 - 414.
[19] Aguilera, R. Talavera. (2009). "Valoración de escenarios futuros a través de la conectividad del Paisaje (Future scenarios assessment through landscape connectivity)." Observatorio Medioambiental 12, pp. 17–36. (in Spanish, abstract version in English)
[20] M. Alberti, P. Waddell. (2000). "An integrated urban development and ecological simulation model." Int. Assess. 1, pp. 215–227.
[21] S. Berling-Wolf, J. Wu. (2004). "Modelling urban landscape dynamics: a case study in Phoenix, USA." Urban Ecosyst. 7, pp. 215–240.
[22] J. Geoghegan, L.A. Wainger, N.E. Bockstael, (1997). "Spatial landscape índices in a hedonic framework: an ecological economics analysis using GIS." Ecol. Econ. 23, pp. 251–264.
[23] X. Li, Q. Yang, X. Liu, (2008). "Discovering and evaluating urban signatures for simulating compact development using cellular automata." Landsc. Urban Plann. 86, pp. 177–186.
[24] K. Gibert, M. Sànchez-Marrè, (2011). "Outcomes from the iEMSs data mining in the environmental sciences work shop series." Environmental Modelling & Software, 26 (7), pp. 983-985.
[25] J.P. Rossi, I. van Halder, (2010). "Towards indicators of butterfly biodiversity based on a multiscale landscape description." Ecol. Indic. 10, pp. 452–458.
[26] Jiang, F., Liu, S., Yuan, H., & Zhang, Q. (2007). Measuring urban sprawl in Beijing with geo-spatial indices. Journal of Geographical Sciences.
[27] Sierra Club. (1998). The Dark Side of the American Dream. Research Report. http://www.sierraclub.com.
[28] USA Today. (2001). A Comprehensive Look at Sprawl in America. http://www.usatoday.com/news/sprawl/ main.htm.
[29] Feranec, J., Jaffrain, G., Soukup, T., & Hazeu, G. (2010). Determining changes and flows in European landscapes 1990–2000 using CORINE land cover data. Applied Geography.
[30] P. M. Torrens, M. Alberti.(2000) .Measuring sprawl. CASA Paper 27. London: Centre for Advanced Spatial Analysis, University College London.
[31] Nelson, A. C. (1999). Comparing states with and without growth management: analysis based on indicators with policy implications. Land Use Policy, 16, 121–127.

[32] Sutton, P. C. (2003). A scale-adjusted measure of ''urban sprawl'' using nighttime satellite imagery. Remote Sensing of Environment, 86, 353–369.
[33] Fulton, W., Pendall, R., Nguyen, M., & Harrison, A. (2001). Who sprawls the most? How growth patterns differ across the US. Washington, DC: The Brookings Institution Center on Urban and Metropolitan Policy.
[34] Masek, J. G., Lindsay, F. E., & Goward, S. N. (2000). Dynamics of urban growth in the Washington DC metropolitan area, 1973–1996, from Landsat observations. International Journal of Remote Sensing, 21, 3473–3486.
[35] Pendall, R. (1999). Do land-use controls cause sprawl? Environment and Planning B, 26(4), 555–571.
[36] Galster, G., Hanson, R., Wolman, H., Coleman, S., & Freihage, J. (2001). Wrestling sprawl to the ground: defining and measuring an elusive concept. Housing Policy Debate.
[37] Cutsinger, G. Galster, H. Wolman, R. Hanson, D.(2005) .Towns Verifying the multi-dimensional nature of metropolitan land use: Advancing the understanding and measurement of sprawl Journal of Urban Affair.
[38] Angel, S., Parent, J., & Civco, D. (2007). Urban sprawl metrics: an analysis of global urban expansion using GIS. Proceedings of ASPRS 2007 Annual Conference, Tampa, Florida May 7–11.
[39] Fan Zuojiang, Cheng Jicheng, Li Qi. (1997). Study on urban growth by using RS and GIS analysis. Remote Sensing Information.
[40] Liu Shenghe. (2002). Spatial pattern and dynamic mechanism of urban land use growth. Progress in Geography.
[41] Yang Yingbao, Jiang Nan, Su Weizhong, (2005). Dynamics of landscape ecology in Nanjing city revealed by RS and GIS. Resources and Environment in the Yangtze Basin, 14(1).
[42] Huang Yue, Chen Xi, Bao Anming et al. (2006). Urban sprawl pattern and spatial features of Urümqi City during the last 15 years. Journal of Glaciology and Geocryology.
[43] Forman, Ernest H.; Saul I. Gass .July 2001. The analytical hierarchy process—an exposition. Operations Research 49 (4):
[44] 469–487.doi:10.1287/opre.49.4.469.11231.
[45] JIANG Fang, LIU Shenghe, YUAN Hong, ZHANG Qing. 2007. Measuring urban sprawl in Beijing with geo-spatial indices. Journal of Geographical Sciences, 17(4), pp.469–478.
[46] K.C. Seto, M. Fragkias, (2005). "Quantifying spatiotemporal patterns of urban land-use change in four cities of China with time series landscape metrics." Landsc. Ecol. 20, pp. 871–888.

4. Physical Driving Factors of Urban Sprawl Using the Logistic Regression Model

∗ This chapter is based on the following paper:

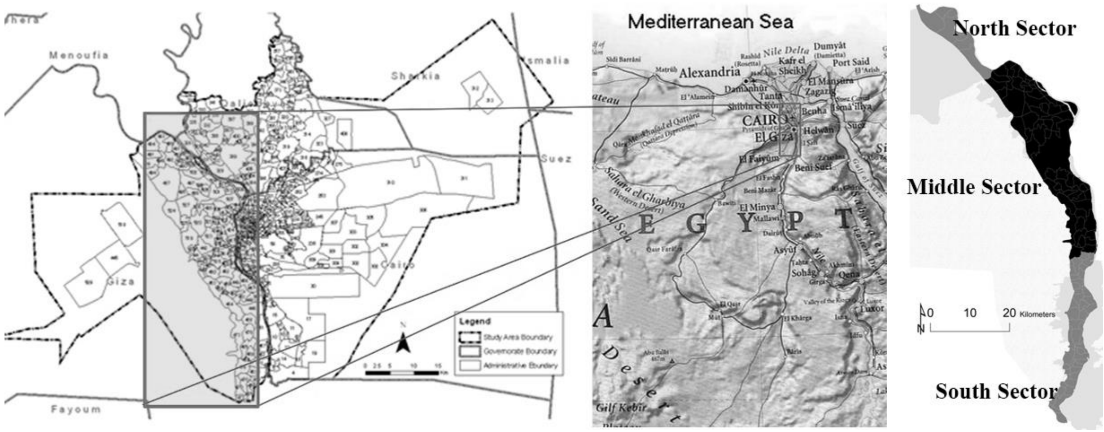
Osman, T., Divigalpitiya, P. & Arima, T., 2016. Driving factors of urban sprawl in Giza governorate of the Greater Cairo Metropolitan Region using a logistic regression model. International Journal of Urban Sciences, 20(2), pp.206–225. Available at: http://dx.doi.org/10.1080/12265934.2016.1162728.

Abstract

Since the 1950s, The Greater Cairo Metropolitan Region (GCMR) has witnessed an unprecedented rate of urban sprawl that has been mainly concentrated in arable lands against urban planning regulations, and has presented a critical challenge to the urban environment and serious corrosion for arable lands. Thus, the need to identify the driving factor of sprawl is crucial to understand the future of the GCMR urban environment and to overcome the serious challenges of rapid urbanization. We focused on the Giza Governorate as a critical area in the GCMR and divided it into 3 sub-sectors to collect data and analyze. A primary list of driving factors was identified by literature review. Later this list was narrowed down to 7 factors after interviews with local urban experts and consideration of the availability of data. Next, a logistic regression analysis was used to evaluate those factors with data derived from existing maps and remotely sensed data for the period of 2004 - 2013. An operating characteristic (ROC) evaluation of the logistic regression analysis gave high accuracy rates for the entire study area. The findings of the research revealed decreasing significance of the CBD and Nile River as drivers of sprawl. The most significant factors according to the analysis were neighborhood factors, local urban centers, and accessibility factors of distances to urban uses and major roads. The research suggests more future urban expansion by the existing urban cores and along major roads, leading to more informal urban settlements. It also points to the possibility of persistent deterioration in the urban built environment and agricultural lands. Thus, these findings should be applied to actual urban planning policies, and development regulations should be strengthened to protect the urban environment from further deterioration.

Keywords: urban sprawl, Driving Factors, Logistic regression, GCMR

4.1 Introduction



(A) Location of Giza governorate within Egypt (B) Study area sectors

Figure 4.1 Location of study area

Due to rapid population growth in developing countries, metropolitan regions have experienced rapid urban expansion during the last five decades. This expansion caused a deterioration of the built environment and had negative socioeconomic impacts, such as the loss of agricultural lands, the transformation of natural ecosystems, and climate change [1-4]. On the other hand, urbanization supports socio-economic development and improvements in the quality of life of citizens [5]. Since the 1950s, urban development in developing countries has continued to be faster than in advanced countries [6]. This demands the establishment of a system to manage the accompanying urbanization process to promote the needs for sustainable development [7]. Consequently, the gross amount of global urban areas has quadrupled over the last four decades of the twentieth century [8]. Presently, more than 50% of world's population lives in urban areas, and this number is estimated to become 67.2% by 2050 [9]. Although urban uses constitute less than 3% of the earth's surface, the ecological and environmental impacts of urban sprawl have global consequences [10].

Since the 1950s, Egypt has witnessed rapid urbanization that has caused an unplanned urban expansion of residential, industrial, and commercial uses around major cities. Unplanned residential uses accommodate between 12-17 million inhabitants, or about 40–50% of Egypt's urban population [11]. Despite 30 years of efforts by the government to manage sprawl, unplanned settlements around the Greater Cairo Metropolitan Region (GCMR) became a home for more than 7 million people by 1998 [12,13]. In 2006, unplanned residential areas in the GCMR were a home for more than 65% of the total population of the GCMR. The ratio of population growth in these unplanned areas was higher than other Egyptian cities, who saw an increase of 2% between 1996 and 2006 [14, 15].

Research based on satellite images detected that the surface area covered by urban sprawl in the GCMR between 1991 and 1998 grew by 3.4 % per annum, while the population living in the informal areas grew by 3.2 % per annum (200,000 people per annum). On the other hand, between 1986 and 1996, the population growth rate of informal settlements reached 3.4% per year, as compared to 0.3% in informal areas. And the growth in informal areas was estimated to be 3.2% per year, compared to 1.1% in formal areas [12, 13]. MOP & GTZ, 2004 [16] claimed that the erosion of arable lands since 1980 has been 1 million Acres, which represents around 12% of the total agricultural land in Egypt. El-Hefnawi, 2005 [17] estimated the value of all arable lands converted to informal areas was US$ 46.2 billion, in addition to the US$ 63.1 billion for the cost of the 7.9 million informal buildings.

In this paper, we define urban sprawl in Giza as the uncoordinated and unauthorized urban development of the main core of the GCMR into the countryside. The research on urban sprawl requires further efforts, especially in developing countries [18,19]. The study of the spatial and temporal dynamics of urbanization due to human activities requires an integration of the driving factors of urbanization to models [20]. During the last three decades, many pieces of research have been carried out all over the world to identify the spatial patterns, driving factors, and ecological and social implications of urban sprawl [8]. Particularly in developing countries, there has been a growing interest in identifying the impacts of sprawl and identifying driving factors to develop successful urban plans and management policies [21].

Numerous methods have been used to identify the factors of sprawl, such as canonical correspondence analysis [22], multiple linear regression [23], analytic hierarchy process [24], bivariate regression [25], and logistic regression [26]. The most widely used tool has been logistic regression, which assumes a linear interconnection among dependent and independent variables [27]; the outcome of a logistic regression can immediately be utilized to understand the prospects of sprawl [28]; and it is a useful method to deal with binary dependent variables.

Statistical interconnections among land-use alterations and a set of descriptive variables are the main features of land-use models [29]. Previous studies have showed that the driving factors of land-use changes have varied significantly among developing countries, and among agricultural and urban areas [4, 30].

To identify all of the possible factors affecting urban sprawl during the period of 2004-2013 (Figure. 1-B) in three study sectors in Giza, this study selected 7 variables that cover both physical and locational aspects, in addition to the effects of various socioeconomic aspects. There several auxiliary algorithms such as auto Logistic, smoothed Logistic, and fractal analysis for analyzing the relationship between land-use alterations and related driving forces [28, 31].

In this research, the classic Logistic model was applied for its effectiveness, and being widely used in similar research. And the ROC method was used for the validation of the model [31].

4.2 Methods and data

4.2.1 Case study

This paper chose the Giza governorate as the case study due to its sub-spatial sprawl in the last four decades. The sprawl pattern in this area has not been previously examined. The Giza governorate is located in the Nile River valley and is bordered by desert from the west (Figure 4.1). Giza is the western part of the GCMR, which consists of the entire of Cairo governorate (east of the Nile), the Giza governorate (west of the Nile), and two urban districts of Qaliubia governorate (north of Cairo) (Figure 4.1). Cairo is an urban governorate with 26 districts. Giza is a rural governorate with 5 urban districts. Qaliubia is a rural governorate with 2 urban districts, and Shubra El Kheima is a village in the outer administrative area of GCMR. The urban plans of the GCMR have been organized by the national-level General Organization for Physical Planning (GOPP). For running businesses and daily governance issues, the administrations of the GCMR region are managed by the three governorates and their executive districts.

Table 4.1 Population Growth in GCMR between 1947-2006

Census	Giza Gov. (Million)	Cairo Gov. (Million)	Qaliubia Gov. (Million)	Total GCMR (million)	GCMR growth (%)
1947	0.668	2.062	0.281	3.013	n/a
1960	1.118	3.358	0.434	4.910	1.82
1966	1.420	4.232	0.560	6.211	4.50
1976	2.137	5.074	0.879	8.090	2.68
1986	3.332	6.069	1.460	10.860	2.99
1996	4.273	6.789	2.081	13.144	1.93
2006	5,131	7,787	3,059	15977	2.18

The Giza governorate is categorized as multifunctional area, based on its role as the political center for all of Egypt. The Giza governorate is located in the western part of the GCMR, and it is the economic, industrial, and service capital of Egypt. Despite the efforts of governmental urban strategies in Egypt, the Giza governorate has had rapid but haphazard urban sprawl over the last four decades. Corruption, political disorder, and a turbulent economic situation may have influenced the urban planning that caused enormous sprawled areas. Consequently, the main concern for the Giza governorate includes rapid urban sprawl and the loss of productive arable lands, which has created socioeconomic and environmental troubles.

Table 4.2 Urban space and population growth in the Giza sectors 1984, 2004, and 2013

Study sector	1984		2004		2013	
	Urban (ha)	Population	Urban (ha)	Population	Urban (ha)	Population
North	187,37	51240	588,26	95323	891,10	111814
Middle	8354,80	1807909	12962,04	3363552	18470,98	3945166
South	861,70	237512	1770,80	441883	2773,10	518292

4.2.2 Research study sectors

The Egyptian administrative hierarchy of urban municipalities follows a centralized system that was introduced in the 1960s during the socialist regime. Municipal budgets, transportation networks, census data are maintained based on this centralized system of hierarchy. We have followed this hierarchy and divided the main study area of the Giza governorate into three sectors, to collect data, conduct field surveys, conduct questionnaire surveys, and analyze and explain the output of this research. The middle study sector is the main urbanized area of the Giza governorate, covered by the metropolitan public transportation network and connecting it with the Cairo CBD. The north and south sectors are semi-urbanized areas with similar land-use characteristics and are outside of the public transportation coverage, although they are part of the GCMR.

The urban sprawl rate in the Giza governorate reached an unprecedented level in all of the three study sub-sectors in comparison with the whole of the GCMR during the period of 1984-2013 (Table 4.5). In the north sector, the urban area increased from 187 ha to 588 ha, with an annual average urban growth rate of 10.72%. Also, the population growth rate was 2.3% during the period of 1984-2004. In addition to that, the urban area increased from 588 ha to 891 ha, with an annual average growth rate of 5.7% and an annual population growth rate of 1.9% from 2004 - 2013. In the middle sector, the urban area increased from 8,354 ha to 12,962 ha, with an annual average growth rate of 2.76% and an average population growth rate of 2.15% from 1984-2004. The urban area increased to 18,471 ha with an annual average growth rate of 4.7% and an annual population growth rate of 1.83% during the period of 2004-2013. In the southern sector, the urban area increased from 861 ha to 1,771 ha with an annual average growth rate of 5.28% with a population growth rate of 2.25% from 1984 -2004. During the period of 2004-2013, the urban area increased to 2,773 ha with an annual average growth rate or 6.3% while the population growth rate was 1.95%. For the last 9 years, the total urban area increased by 51.5% in the north sector, 42.5% in the middle sector, and 56.6% in the southern sector, with an average total rate of 44.47% in the whole study area (Figure 4.2).

4.2.3 Identifying the driving factors of Urban Sprawl

Table 4.3 Interview questions with GOPP urban experts

Question	How to answer
From the submitted list of 26 sprawl driving factors, Choose the most appropriate for Giza case study.	Choose by Adding marks
In case you have additional sprawl driving factors not mentioned in the submitted list, please add them on the next page.	Write Describing

Table 4.4 Primary driving factors set based on interviews with urban experts

Driving Factors	Type of factor
Economic activities	socioeconomic
Capital income	socioeconomic
Housing rent	socioeconomic
Population density	socioeconomic
Number of urban cells within a 7 by 7 Neighborhood	Physical
Distance to the nearest Excising urban area (m)	Physical
Distance to the nearest major road (m)	Physical
Distance to CBD (m)	Physical
Distance to the nearest County Center (m)	Physical
Distance to Nile River (m)	Physical
Cost Distance to the nearest Urban Center	Physical

In advance, a list of the possible 26 driving factors of sprawl in the Giza governorate was derived from researchers who have carried out similar cases in other developing countries [30-32]. The first screening of the first 26 driving factors, which were collected from literature review, showed a high correlation between several factors. Then, we re-identified the appropriate factors of urban sprawl in the study are from interviews with urban experts in the GOPP. The interview was performed with two urban experts who had more than 5 years of experience in preparing development plans for the Giza governorate. The interviews were conducted over two days with the two experts. On the first day, the urban experts were interviewed individually to brainstorm with a guided questioner (Table 4.3) and choose the effective driving factors of sprawl in Giza according to their professional expertise. On the second day, both experts were gathered at the same session to decide the final list of sprawl factors. The urban experts were given freedom to add or subtract from the given set of the driving factors, which was prepared earlier from literature review. The urban experts successfully determined a set of 11 driving factors to be included in the logistic regression model.

We found that reliable socioeconomic data is scarce for the local municipalities in our study, as is the case generally with developing countries such as Egypt. Abebe, 2013 [33] found the same thing in a similar case study concerning Uganda. He used only the physical driving factors in his logistic regression model to quantify sprawl in the Kampala region. Although the socio-economic factors are important, the physical factors could reflect the aggregate effects of the socioeconomic factors on such research cases [34-36]. The socioeconomic factors (population density, GDP, Economic growth rates, employment rates, and rent prices) that shape the patterns of urban growth in the Atlanta region reflect the physical conditions of this area, such as the major highways, major urban economic activity centers, existing land-use status, and land-use conservation patterns. Therefore, in this paper we applied 7 physical driving factors in the logistic regression model, which had reliable data in the Giza case study area.

4.2.4 Data collection

This research used primary and secondary data to accomplish the goals of the study. Although some secondary data are gathered from literature reviews and open source websites, we used fieldwork to compare this secondary data with the current conditions in real life and to update other data, particularly roads networks. This fieldwork was performed from June 2012 to September 2012 and updated in September 2014 in the Giza governorate.

Two Google earth images from 2004 and 2013 were used to detect the patterns of alterations of the urban land in the study area. These images had a spatial accuracy of 0.6m. This high accuracy of source data makes it convenient to compare changes land-use and there patterns. After that, polygons of uses, including agricultural land, urban land, main road networks, and water bodies, were digitized from the Google earth images (www.googleearth.com) and then converted to raster data on a GIS platform. Most GIS data, such as the location of urban areas and existing built up areas, are derived from Google Earth images according to the data gathered from local experts during fieldwork. Other data, such as administrative boundaries, detailed land uses types, CBD, Main urban centers, local County centers, and local road networks, are obtained from the GOPP (www.gopp.gov.eg). All datasets used in this study are geometrically referenced to the WGS 1984, UTM zone 36 projection systems. Detailed descriptions of the characteristics of all images used in this study are summarized in tables 4.5 & 4.6 below. A logistic regression model with 7 independent driving factors (X1–X7) is calibrated with the help of GIS software using full data points within the mask of 122 urban areas divided into three sectors. The model calibration was conducted using a raster data set with 60 m resolution. There were 47,900 data points in each layer, and 8 layers in total.

Table 4.5 Set of satellite images gathered from the study area.

S/N	Aerial	Year	Scale/Resolution	Sources
1	Google Earth Image	October,	0.6m by 0.6m	Google Earth website accessed on 10 October,
2	Google Earth Image	October,	0.6m by 0.6m	Google Earth website accessed on 10 October,

Table 4.6 Set of spatial data (vector data) used for the study area

Spatial data	Source
Urban uses 2004	Derived from Google Earth image
Urban uses 2013	Derived from Google Earth image
Agricultural lands 2004	Derived from Google Earth image
Agricultural lands 2013	Derived from Google Earth image
Major Roads	Derived Google Earth image
Local roads	(GCMR) geodatabase /GOPP
Main urban centers	(GCMR) geodatabase /GOPP
County centers	(GCMR) geodatabase /GOPP
CBD area	(GCMR) geodatabase /GOPP
Detailed land uses, 2004	(GCMR) geodatabase /GOPP
Administrative	(GCMR)geodatabase /GOPP
Water bodies	Derived from Google Earth image

A. Dependent variables

In this model, maps of the binary land use of urban sprawl between 2004-2013 were used as dependent variables to perform the logistic regression analysis. These maps had two land use classes, agricultural land 0 and urban land 1. This model assumed that land-use alters only from agricultural to urban land-uses because of the very low probability of land-use conversion from built-up land to non-built-up land in developing countries like Egypt.

B. Independent variables

The independent variables for the regression analysis were selected based on location factors. A focal statistic tool in Arc GIS 10.1 was used to calculate the proportion of built-up area (P_URBAN) within a 7X7 neighborhood. The size of the neighborhood window was decided according to the most widely used window sizes in dynamic simulation models where sizes are usually 3 X 3, 5 X 5, or 7 X 7 [28]. The Distance to Existing urban uses (DIST_Euu), distance to CBD (DIST_CBD), distance to major roads (Dist_Mjrd), cost distance to the nearest urban center (C_Dist_Nuc), distance to county centers (Dist_Cc), distance to the Nile River (Dist_Nr), and the cost distance were calculated by the Euclidean distance tool in Arc GIS 10.1. A Euclidean distance tool measures the shortest distance from the center of the source cell to the center of each of the neighboring cells.

Table 4.7 Final Set of variables included in the logistic regression model

Variable	Meaning	Nature of variable
Dependent		
Y	(Y=0) no urban Sprawl; (Y=1) urban growth	Dichotomous
Independent		
X1 (P_URBAN)	Number of urban cells within a 7 by 7 Neighborhood	Continuous
X2 (DIST_Euu)	Distance to the nearest Excising urban area (m)	Continuous
X3 (Dist_Mjrd	Distance to the nearest major road (m)	Continuous
X4 (DIST_Euu)	Distance to CBD (m)	Continuous
X5 (Dist_Cc)	Distance to the nearest County Center (m)	Continuous
X6 (Dist_Nr)	Distance to Nile River (m)	Continuous
X7 (C_Dist_Nuc)	Cost Distance to the nearest Urban Center	Continuous

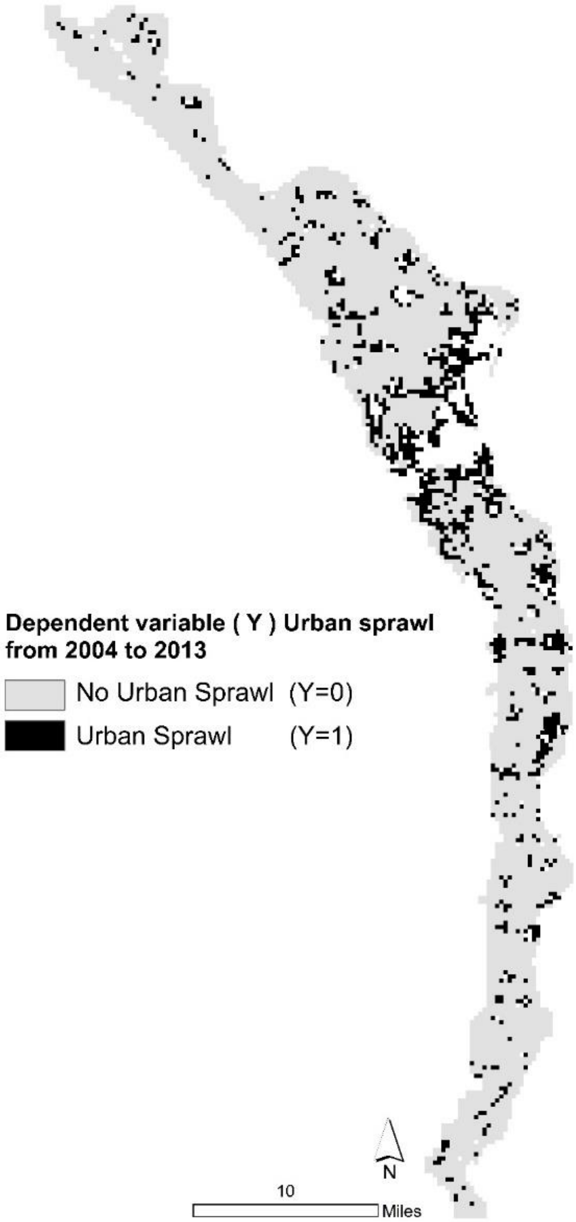
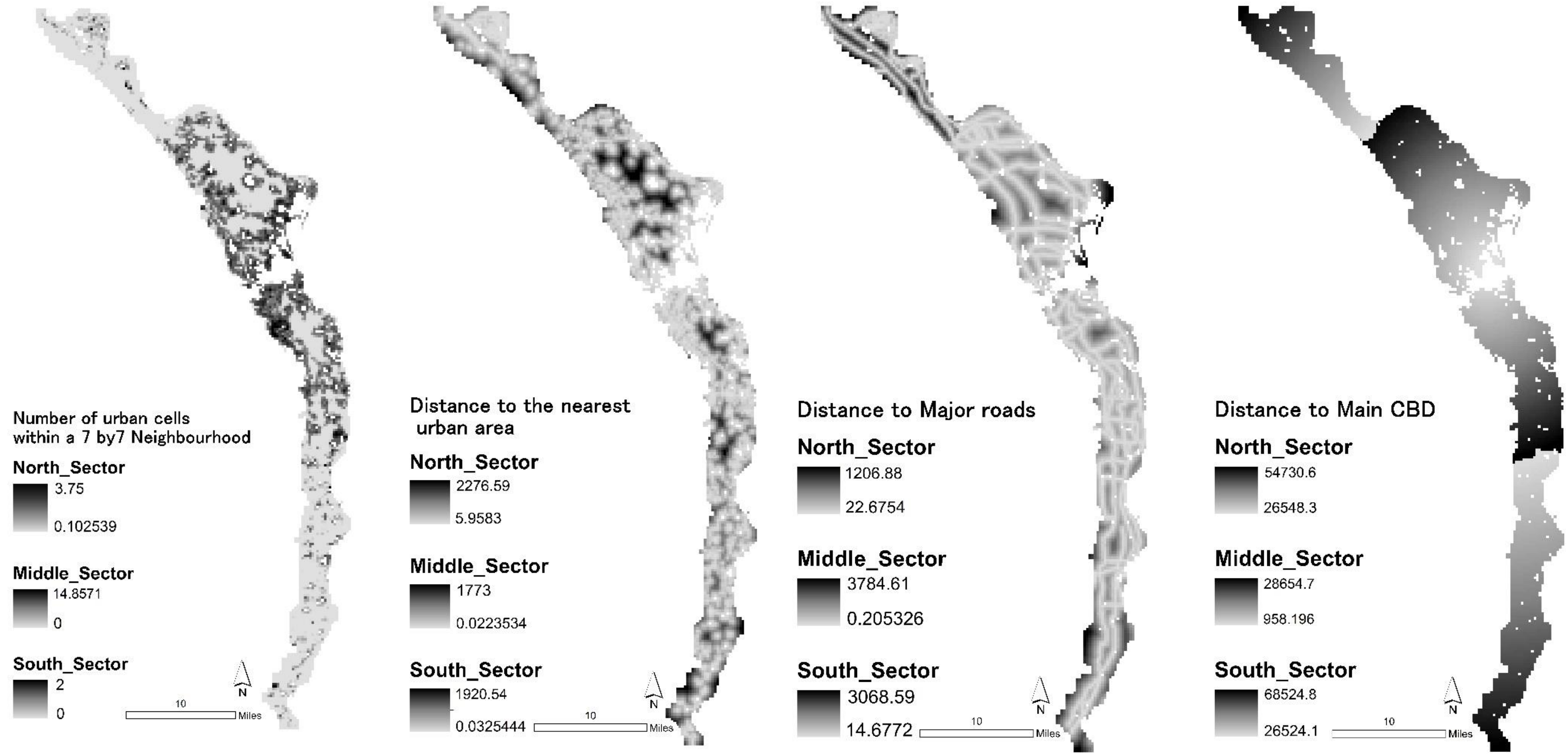
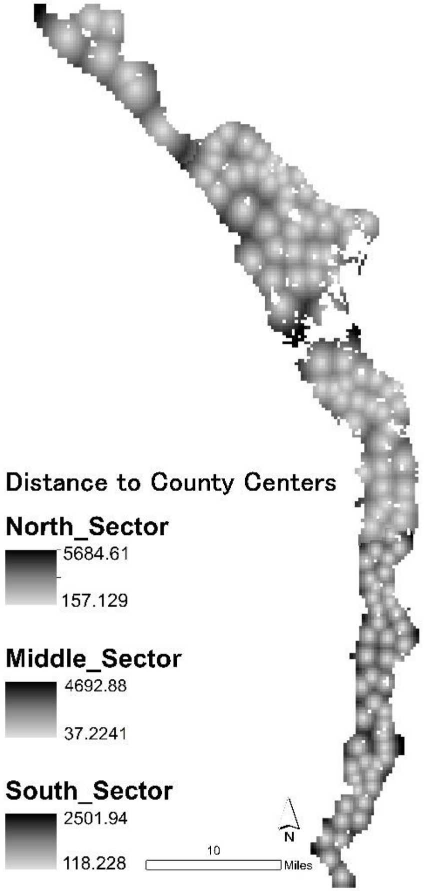


Figure 4.2 Dependent variable Y – urban sprawl from 2004 to 2013

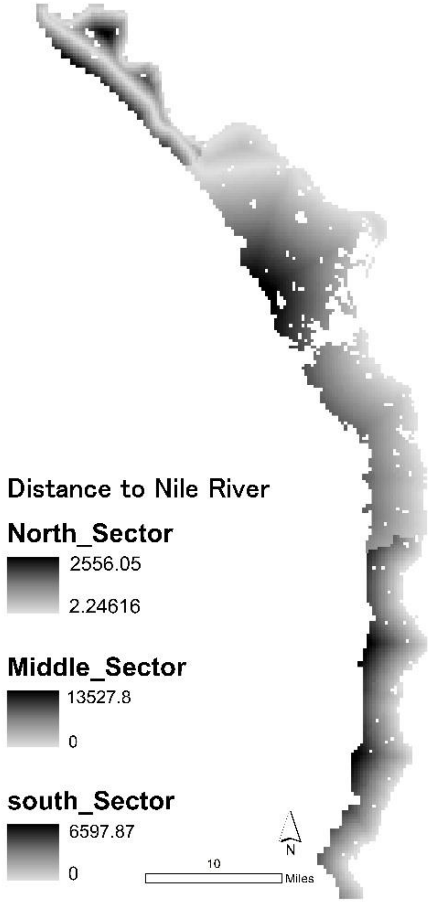


(A) Urban Cell proportion (B) Dist. Urban areas (C) Dist. Major roads (D) Dist. CBD

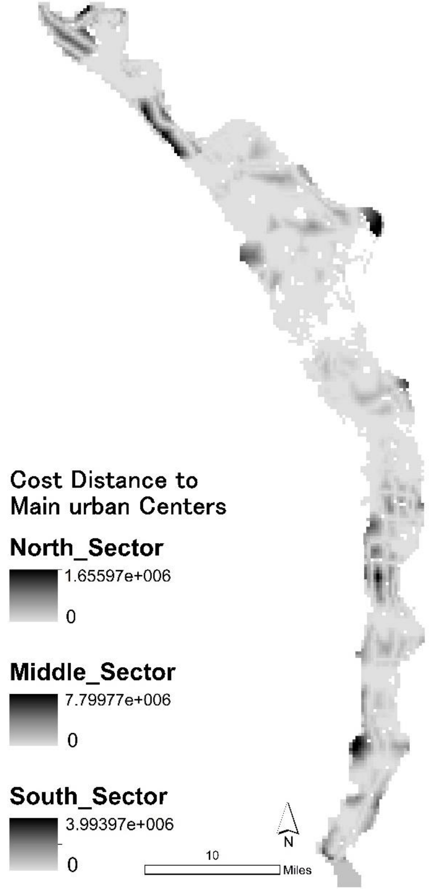
Figure 4.3 Layers of independent variables



(E) Dist. County Centers



(F) Dist. Nile River



(G) Cost Distance

Figure 4.3 Layers of independent variables

4.3 Logistic regression model

We used the logistic regression model to compare urban Sprawl in the Giza governorate with the sprawl potentials influenced by physical driving factors. The nature of the alteration of the land use of a cell is dichotomous: either there is existence of urban sprawl or not. According to Kleinbaum, 1994 [37] a logistic curve can explain if binary values 1 and 0 are applied to symbolize urban sprawl and no urban sprawl.

4.3.1 Calibration of the Logistic Regression Model

The aim of the calibration of the logistic regression model in this study was to detect the ideal resolution for modeling. We applied raster GIS data aggregation and pixel superfine purposes on the data layers to correct for the impacts of space, which is used when multi-resolution datasets were created for multi-scale modeling. The multi-resolution modeling process from a 60 m cell size to a 360 m cell size is a procedure of easing the spatial impact by a set of spatial lags from the first order of 60 m to the 6th order of 360m. The impact of spatial reliance at a resolution of 360 m must be less than that at 60m since the attribute comparability is weaker as spatial lags proceed from the first order to a higher order. With a resolution of 360 m in the north sector, the total number of cells was 6,168, while the number of altered cells from non-urban to urban for variable Y (1 = urban Sprawl) was 61, accounting for 0.98% of the total number of cells. In the middle sector, the total number of cells was 21,785, and the number of cells which were converted from non-urban to urban Y (1 = urban Sprawl) was 1,042, accounting for 4.8% of the total number of cells. Finally, in the south sector, the total number of cells was 10,686, while the number of altered cells from non-urban to urban for variable Y (1 = urban Sprawl) was 207, accounting for 0.95 % of the total number of cells.

4.3.2 Goodness of Fit of the model

Table 4.8 shows the goodness of fit of our model. The Cox and Snell R Squared values and the Nagelkerke R Squared values are analogous indicators to the R2 statistics of the linear regression. So, the closer R2 value to 1, the closer the model is to certainty. The maximum likelihood estimator [38] was computed to measure the Goodness of Fit of our model. The output of the logistic model given in Table 4.8, α = 0.05 levels, proved that the 7 driving factors are significant enough. A probability map was created using the output of the model and a residual map was computed to estimate the extent to which autocorrelation had been decreased. Cox & Snell R Squared and Nagelkerke R Squared were computed to further test the goodness of fit of our model. The R square values were between 0.2 and 0.4, which reflects the accuracy of the model [39]. The Cox & Snell R2 value for the whole model was 0.700, which refers to a very good fit in the north sector, while in the middle sector it was 0.572, which also proves to be a good fit. Finally, it was 0.678 in the south sector, also referring a very good fit.

Table 4.8 Goodness-of-fit statistics of the logistic regression in the three sectors of Giza

Statistics	Case study		
	North sector	Middle sector	South sector
Log likelihood -2	1134.340	11696.027	2697.864
Cox & Snell R Squared	0.700	0.572	0.678
Nagelkerke R Squared	0.933	0.763	0.904
Overall correct model percentage	95.6%	88.6%	94.5%

By using the Nagelkerke R Squared method we found that R2 indicates an excellent fit in the north and south sectors by scoring 0.933 and 0.904, respectively. It was 0.763 in middle sector, which still represents a very good model fit.

4.3.3 Multicollinearity analysis

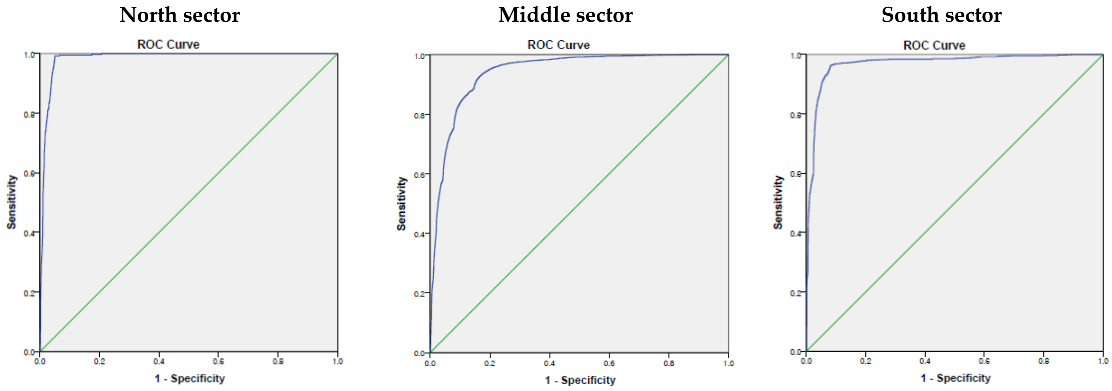
To eliminate redundant driving factors from our model and preserve the constancy of our coefficients, a multicollinearity test was performed for each set of factors in the three study sectors. The analysis was performed in SPSS 20 by regressing one of the independent variables against the residual six driving factors in a repeated mechanism. As such, each variable was distinguished for multicollinearity. None of our model driving factors scored VIF >10. The analysis shows that all variables give VIF <5, which is a good outcome. The outcome of the multicollinearity analysis for all the study sectors is shown below. The model established in this paper is consistent with the outcome of similar prior research [28, 31, and 40].

Table 4.9 Results of the multicollinearity analysis

Variables	Description	VIF North	VIF	VIF South
X1 (P_URBAN)	Number of urban cells within a 7 by 7	1.192	1.694	1.241
X2 (DIST_Euu)	Distance to the nearest Excising urban area (m)	3.091	2.543	1.007
X3 (Dist_Mjrd	Distance to the nearest major road (m)	3.133	3.388	1.075
X4 (DIST_Euu)	Distance to CBD (m)	4.476	3.344	1.124
X5 (Dist_Cc)	Distance to the nearest County Center (m)	1.050	4.675	1.099
X6 (Dist_Nr)	Distance to the Nile River (m)	3.407	3.033	1.045
X7 (C_Dist_Nuc)	Cost Distance to the nearest Urban Center	1.006	1.900	1.027

4.4 Model Evaluation

We used ROC as a calibration method for the probability of urbanization in the Giza governorate. The ROC method is widely used to examine the efficacy of a model. It predicts the occurrence of a phenomenon by emulating a probability image that describes the probability of that phenomenon's occurrence and a binary image displays where that class indeed occurs [41].



Area Under Curve

North sector	Middle sector	South sector
.985	.941	.970

Figure 4.4 ROC curves of the logistic regression model for the three study sectors

4.5 Results and discussion

4.5.1 North sector

Table 4.10 Estimated coefficients and odds ratios of the logistic regression model for the north sector

Variable	Coefficient (B)	Standard error	Odds ratio	Sig.	Exp (B)
X1 (P_URBAN)	2.904	0.130	17.245	0.000	18.245
X2 (DIST_Euu)	-0.005	0.001	-0.005	0.000	0.995
X3 (Dist_Mjrd	-0.001	0.001	-0.001	0.149	0.999
X4 (DIST_Euu)	0.000	0.000	0.000	0.000	1.000
X5 (Dist_Cc)	0.000	0.000	0.000	0.014	1.000
X6 (Dist_Nr)	0.000	0.000	0.000	0.598	1.000
X7	0.000	0.000	0.000	0.000	1.000

The agricultural zones closer to urban cores and major roads had greater potential for developing to urban uses. The number of urban cells within a neighborhood of 7 by 7 cell sizes (X1) had an odds ratio equaled to 17.245. With an increase of 1 urban cell within the neighborhood, the odds of development increase 2.904. The use of a land parcel was influenced by the urban conditions of neighboring areas. Land brokers had tendencies to follow land use attributes and patterns in the existing urban areas where urban sprawl used to be (X2). The estimated odds ratio of urban sprawl probability in agricultural lands around existing urban cores was - 0.005, or- 5/1000, which is less than the sprawl probability in lands farther away from existing cores. Therefore, the odds of urban sprawl declines by 5 if the distance to the nearest existing urban area decrease by 5 meters.

Urban sprawl happens in agricultural lands closer to major roads (X3) that are attractive for low & middle-class residential users and small businesses, such as shops or factories. The model explained that urban sprawl has been taking place in locations with good road accessibility. The odds ratio for the distance to major roads (X3) was -0.001, or- 1/1000. The odds of urban sprawl in an area near the major roads were 1,000 times the odds in an area 1 km further away from major roads. The road impact contributed to ribbon and strip developments. This explains how the business land-use, and low & middle class residential land-use are connected to main urban centers and employment sites in GCMR. The polycentric suburbanizing trend in the Giza governorate was proved by the odds ratios of the following driving factors: distance to the CBD (X4), cost distance to active economy centers (X7), and distance to county centers (x5). The odds ratio for x4, x5, and x7 was 0 for all of them; consequently, there was no impact of the polycentric suburbanizing tendency for urban sprawl in the north sector.

4.5.2 Middle sector

Table 4.11 Estimated coefficients and odds ratios of the logistic regression model for the middle

Variable	Coefficient (*B*)	Standard error	Odds ratio	Sig.	Exp (B)
X1 (P_URBAN)	0.685	0.012	0.984	0.000	1.984
X2 (DIST_Euu)	-0.007	0.000	-0.007	0.000	0.993
X3 (Dist_Mjrd	0.000	0.000	0.000	0.710	1.000
X4 (DIST_Euu)	0.000	0.000	0.000	0.000	1.000
X5 (Dist_Cc)	0.000	0.000	0.000	0.096	1.000
X6 (Dist_Nr)	0.000	0.000	0.000	0.000	1.000
X7	0.000	0.000	0.000	0.000	1.000

The neighborhood factor (X1) in the middle sector had an odds ratio of 0.984. By increasing 1 urban cell within the neighborhood, the odds of development increase by 0.685. Land developers had some tendencies to imitate land use attributes in existing urban areas where urban sprawl tended to occur in locations near the existing urban uses (X2). The estimated odds ratio of sprawl in locations closer to the existing cores was - 0.007, or- 7/1000, which is less than one, against the sprawl in locations farther away from existing urban cores. The odds of urban sprawl decrease by 7 times if the distance to nearest existing urban core decreases by 7 meters. The Major roads had no impact on urban sprawl in the middle sector, and they supported sprawl in the north sector since the nature of sprawl in the middle sector was different and demonstrated a higher effect of existing urban uses (X2). In the middle sector, land plots around major roads were 100% developed by formal, high-class residential uses, mega-commercial malls, and regional service centers, which are typical lands located around major roads in the middle sector. This pattern of development was strongly related to the value of the land, whether formal or non-formal. In addition to that, the odds ratios of the driving factors (distance to the CBD (X4), cost distance to active main urban centers (X7), distance to the Nile River (X6), and distance to county centers) scored 0. All sprawl locations were highly connected by cheap public transportation in the middle sector. Consequently, the results of the model proved that there were no wide gaps in location centrality in the middle sector that could impact urban sprawl.

4.5.3 South sector

Table 4.12 Estimated coefficients and odds ratios of the logistic regression model for the south

Variable	Coefficient	Standard error	Odds ratio	Sig.	Exp (B)
X1 (P_URBAN)	1.935	0.060	5.926	0.000	6.926
X2 (DIST_Euu)	-0.008	0.000	-0.008	0.000	0.992
X3 (Dist_Mjrd	0.000	0.000	0.000	0.008	1.000
X4 (DIST_Euu)	0.000	0.000	0.000	0.000	1.000
X5 (Dist_Cc)	-0.001	0.000	-0.001	0.000	0.999
X6 (Dist_Nr)	0.000	0.000	0.000	0.323	1.000
X7 (C_Dist_Nuc)	0.000	0.000	0.000	0.301	1.000

Agricultural Land parcels surrounded by existing urban areas were more likely to be converted to urban uses. The number of the urban cells neighborhood factor (X1) had an odds ratio of 5.926. With an increase of 1 urban cell within the neighborhood, the odds of urban sprawl increase by 1.935. Urban sprawl occurs in locations around existing urban uses (X2). The value of odds ratio for X2 was - 0.008, or- 8/1000, which is less than one, and the probability of sprawl in an area closer to existing urban cores was higher than the sprawl probability in a location farther away from existing cores. So, the odds of urban sprawl decrease by 8 times if the distance to the nearest existing urban area increases by 8 meters. Unplanned urban sprawl occurs closer to county urban centers (X5) where residential areas, small businesses, and informal factories are concentrated. The odds ratio of distance to county centers (X5) was -0.001, or- 1/1000. The odds of urban sprawl closer to urban areas were 1,000 times larger than the odds of urban sprawl in an area 1 km further away from that county urban center. This was an indication of the dragging factor nearby the centers where infrastructure, urban services, and daily commercial services are concentrated. The distance to the nearest major roads (X3), the distance to the CBD (X4), and the cost distance to active main urban centers (X7) scored 0, which means there was no impact of decentralization or polycentric suburbanizing trends in the southern sector of the Giza governorate. In an addition to this, the absence of a public transportation system in the south sector concentrated sprawl around existing urban centers to use essential services. Consequently, the importance of major roads decreased, since local people preferred to use the shortest local roads for their daily trips for services and business. Therefore, the impact of major roads was limited on urban sprawl in such locations.

Three of the seven factors (X3, X4 and, X6) had no significant effect on urban sprawl in Giza. The experts suggested that the (X6) Distance to the Nile River was a driving factor, whereas the significance (B) of this factor in the model scored 0 in all three study sectors. This could be interpreted based on [12,42] the Nile River representing a significant historical driving factor for urban development for thousands of years in Egypt, but this significance has diminished as the economic activities shifted from agriculture and other primary activities, that demand proximity to the Nile, to more modern urban activities like services and industries.

In addition to this, the significance of the (x4) Distance to the CBD was 0 in all three of the study sectors, which refer to the decay of significance of the formal CBD for this pattern of urban development. This could be related to the pattern of urban sprawl in Giza agricultural lands, which mainly consists of low-cost housing units that were established outside planning regulations. These informal areas have low-cost commercial, entertainment, transportation hub, and primary services, which are usually available outside of the formal CBD as a cheap alternative to the formal one. This observation is compatible with the special pattern of informal development needs [12,43]. The importance of a formal Giza CBD could be related to high-class residential uses that can afford these expensive services.

Moreover, the local residents in such sprawled areas use special types of public transportation modes [43]. These modes are usually unlicensed and use local and unpaved roads that are shorter and outside of the government's control. However, these modes are compatible with nature of these areas, especially for their cheap costs and the flexibility of movement in the local network. Therefore, the major road network that used this model to calculate the cost distance has no importance in such areas. This could explain why the model scored 0 as the value of (B) for the (X7) Cost Distance to the nearest Urban Center in all three study sectors. The disappearance of the importance of a major transportation network for low-class housing (the main output of urban sprawl in Giza) could be implied significantly in the middle and south sectors where (B) scored 0 for (X3). These two sectors witnessed high rates of low-class residential sprawl, in contrast with the north sector [44].

4.5.4 Prediction of urbanization probability

The output of urbanization probability in Figure 4.5, is a 0-100 color classification of sprawl probability values. The darker tones indicate the higher probabilities of sprawl. The future of the pattern of urban distribution is easy to identify from this map. Some new urban areas that are far from existing urban areas can be identified. The most probable areas for urban development are closer to the existing urban areas, in addition to the specific probable places around major roads in the north sector.

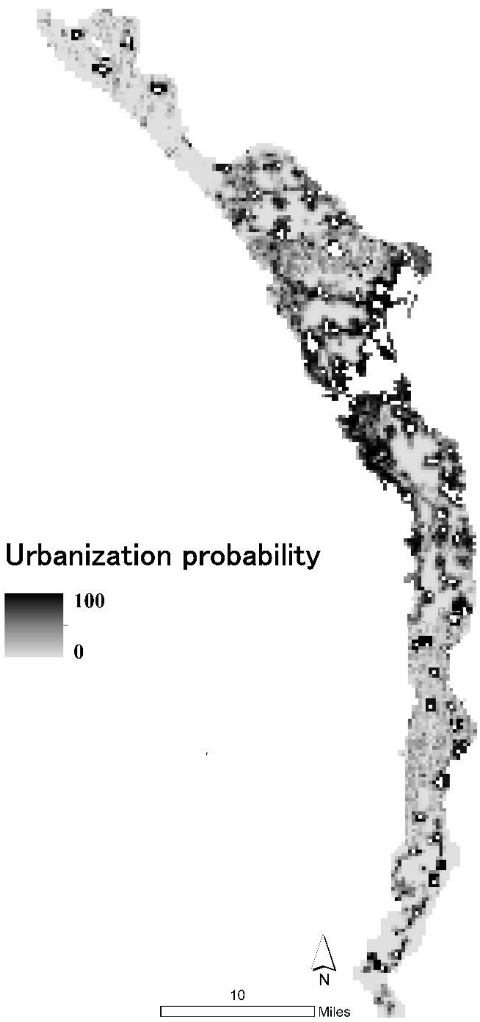


Figure 4.5 Urbanization probability map of the Giza governorate

4.6 Conclusion

The findings of this paper show that the Giza governorate witnessed a significant demand for more buildable lands for urban expansion along its edges in all three study sectors from 2004-2013. During this period, developed land expanded at a rate 16 % higher than the growth of the population. These findings provide proof of the decreased significance of the CBD and Nile River in all study sectors as drivers of sprawl, while the significance of local urban centers has increased. Moreover, we found that accessibility factors, especially the distances to existing urban areas and major roads, are important factors of urban sprawl; although the relative magnitude of the effect varied across all three study sectors. Neighborhood factors have the highest positive effect on urban expansion, indicating that urban expansion tended to take place in locations near developed areas. This means the Giza built environment will keep fast expansion in the future around the existing urban sprawl locations, which will lead to more informal areas and will continue to lead to more deterioration of the urban environment and degradation of agricultural lands.

Local urban municipalities in Giza should identify the potential growth areas around existing urban edges, along major roads, and near local urban centers, as well as prepare urban plans with strict building regulations to prevent future informal settlements. These plans should focus on supporting the potential growth areas with basic services such as water, sanitation, and electricity networks, in addition to educational, health, and public transportation services.

The findings of our study are not only useful to manage sprawl in the GCMR, but also in all similar metropolitan regions in developing countries. The study identified the major factors of urban sprawl and their inter-relationships, which can help control future informal urbanization by controlling the responsible factors. Thus, the GCMR needs a real urban plan, development regulations, and decision support tools to enhance the measures against the rate of urban sprawl and to save productive lands. We recommend that policymakers should continuously update their planning policies to ensure location-based, context-related, and pro-active planning.

To overcome the common issues related to mathematical models for urban growth that have no adequate translation of the results into operational tools for urban planners and policy makers, the results obtained from logistic regression models should be used to identify the tendencies of urban expansion in local municipalities. The suggested method does not have a deterministic outcome, in the sense of identifying exact locational patterns. It merely estimates the probability of development for each area. The proposed methodology could be of use to planning stakeholders because it can be used to provide them with a map that shows development trends.

Community objectives of sustainability in urban growth need to be defined. And those objectives need to be translated to appropriate policies that guide development. The trends of development should be evaluated based on an area's objectives. Additionally, appropriate zoning regulations and policies can be adopted to encourage or discourage development in relevant areas.

This study shows that spatiotemporal variation exists in urban sprawl. However, the results of future research could be much more useful if a simulation model is developed that can model spatiotemporal variations with simulation rules, rather than constant rules for total urban sectors. Lastly, Egypt's land control policy for the protection of prime agricultural lands has proven to have no effect for land protection. However, while we examined the effects of driving factors on urban sprawl, we did not examine the spatial heterogeneity of the driving factors. Thus, future work on the spatial heterogeneity of the influences of the driving factors on urban sprawl is highly recommended.

References

[1] Angotti, T. (1993). Metropolis 2000: Planning, poverty and politics. London: Routledge.

[2] Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., et al. (2001). The causes of land-use and land-cover change: moving beyond the myths. Global Environmental Change, 11, 261–269.

[3] López, E., Bocco, G., Mendoza, M., & Duhau, E. (2001). Predicting land-cover and land-use change in the urban fringe: a case in Morelia city, Mexico. Landscape and Urban Planning, 55, 271–285.

[4] Huang Q H, Cai Y L, Peng J,(2007). Modeling the spatial pattern of farmland using GIS and multiple logistic regression: A case study of Maotiao River Basin, Guizhou Province, China. Environmental Modeling and Assessment, 12(1): 55–61.

[5] Miller, M. D. (2012). The impacts of Atlanta's urban sprawl on forest cover and fragmentation. Applied Geography, 34, 171e179.

[6] Youssef, A. M., Pradhan, B., & Tarabees, E. (2011). Integrated evaluation of urban development suitability based on remote sensing and GIS techniques: contribution from the analytic hierarchy. Arabian Journal of Geosciences, 4 (3–4). doi:10.1007/s12517-009-0118-1.

[7] Jiang, B., & Yao, X. (2010). Geospatial analysis and modelling of urban structure and dynamics (Vol. 99, p. 440). Springer: Netherlands.

[8] Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. PLoS ONE, 6 (8), e23777.

[9] United Nations. (2012). World urbanization prospects: The 2011 revision. Available at: (Last accessed 25.09.14) http://esa.un.org/unpd/wup/index.htm.

[10] Grimm, N., Faeth, S., Golubiewski, N., Redman, C., Wu, J., Bai, X., et al. (2008). Global change and the ecology of cities. Science, 319 (5864), 756e760.

[11] Kipper, R. And Fischer, M., (eds.), 2009: Cairo's Informal Areas: Between Urban Challenges and Hidden Potentials: Facts. Voices. Visions. Chapter 2: Daily Life in Informal Areas, 49-83.

[12] Taher Osman, Takafumi Arima, Prasanna Divigalpitiya (2015a). Measuring urban Sprawl patterns in Greater Metropolitan Cairo Region, Journal of the Indian Society of Remote Sensing. Springer Publications. DOI: 10.1007/s12524-015-0489-6

[13] Séjourné, M. (2006). Les politiques récentes de "traitement" des quartiers illégaux au Caire. PhD Thesis, Université de Tours, France.

[14] Taher Osman, Prasanna Divigalpitiya Takafumi Arima. (2015b). Modeling Urban Growth Scenarios in Cairo Metropolitan Region 2035 , Proceedings of 14th International Conference on Computers in Urban Planning and Urban Management (CUPUM 2015), MIT ,Massachusetts, USA .

[15] Sims, D., & Séjourné, M. (2008). The dynamics of peri-urban areas around greater Cairo: A preliminary reconnaissance. Washington, D.C.: World Bank.

[16] MOP and GTZ, 2004. (Ministry of Planning - German Technical and Financial Cooperation), New Practice of Participatory Local –Development in Egypt's Urban Areas, Policy Paper, Egypt.

[17] El-Hefnawi, A. (2005). Protecting agricultural land from urbanization or managing the conflict between informal urban growth while meeting the demands of the communities. Third urban research symposium on Land Development, Urban Policy and Poverty Reduction. Brasilia, DF, Brazil: World Bank Institute of Applied Economic Research (IPEA).

[18] Al-shalabi, M., Billa, L., Pradhan, B., Mansor, S., & Al-Sharif, A. A. A. (2012). Modelling urban growth evolution and land use changes using GIS based cellular automata and SLEUTH models: the case of the Sana'a metropolitan city, Yemen. Environmental Earth Sciences. doi:10.1007/s12665-012-2137-6.

[19] Jokar Arsanjani, J. (2011). Dynamic land use/cover change modelling: Geosimulation and multiagent-based

modelling (hardback) (series: springer theses) (XVII, p. 139), Springer: Berlin, Heidelberg.
[20] Veldkamp, A., & Lambin, E. F. (2001). Predicting land-use change. Agriculture, Ecosystems & Environment, 85, 1–6.
[21] Long, Y., GU, Y., & Han, H. (2012). Spatiotemporal heterogeneity of urban planning implementation effectiveness: evidence from five urban master plans of Beijing. Landscape and Urban Planning108 (2e4), 103e111.
[22] Fu, B., Zhang, Q., Chen, L., Zhao, W., Gulinck, H., Liu, G., et al. (2006). Temporal change in land use and its relationship to slope degree and soil type in a small catchment on the Loess Plateau of China. CATENA, 65 (1), 41e48.
[23] Seto, K. C., Fragkias, M., Güneralp, B., & Reilly, M. K. (2011). A meta-analysis of global urban land expansion. PLoS ONE, 6 (8), e23777.
[24] Thapa, R. B., & Murayama, Y. (2010). Drivers of urban growth in the Kathmandu valley, Nepal: examining the efficacy of the analytic hierarchy process. Applied Geography, 30 (1), 70e83.
[25] Wu, K., & Zhang, H. (2012). Land use dynamics, built-up land expansion patterns, and driving forces analysis of the fast-growing Hangzhou metropolitan area, eastern China (1978e2008). Applied Geography, 34 (0), 137e145.
[26] Dubovyk, O., Sliuzas, R., & Flacke, J. (2011). Spatio-temporal modelling of informal settlement development in Sancaktepe district, Istanbul, Turkey. ISPRS Journal of Photogrammetry and Remote Sensing, 66 (2), 235e246.
[27] Cheng, J., & Masser, I. (2003). Urban growth pattern modeling: a case study of Wuhan city, PR China. Landscape and Urban Planning, 62 (4), 199e217.
[28] Hu, Z., & Lo, C. P. (2007). Modeling urban growth in Atlanta using logistic regression. Computers, Environment and Urban Systems, 31 (6), 667e688.
[29] Overmars, K. P., & Verburg, P. H. (2005). Analysis of land use drivers at the watershed and household level: linking two paradigms at the Philippine forest fringe. International Journal of Geographical Information Science, 19, 125– 152.
[30] Nong, Y., & Du, Q. (2011). Urban growth pattern modeling using logistic regression. Geo-spatial Information Science, 14 (1), 62-67. doi: 10.1007/s11806-011-0427-x.
[31] Huang, B., Zhang, L., & Wu, B. (2009). Spatiotemporal analysis of ruraleurban land conversion. International Journal of Geographical Information Science, 23 (3), 379e398.
[32] Tayyebi, A., Delavar, M., Yazdanpanah, M., Pijanowski, B., Saeedi, S., (2010). A Spatial Logistic Regression Model for Simulating Land Use Patterns: A Case Study of the Shiraz Metropolitan Area of Iran. In E. Chuvieco, J. Li & X. Yang (Eds.), Advances in Earth Observation of Global Change (pp. 27-42): Springer Netherlands.
[33] Gezahegn Aweke Abebe .(2013).Quantifying Urban Growth Pattern In Developing Countries Using Remote Sensing And Spatial Metrics:A Case Study In Kampala, Uganda, Msc Thesis,Aculty Of Geo-Information Science And Earth Observation, University Of Twente.
[34] Agarwal, C., Green, G. M., Grove, J. M., Evans, T. P., & Schweik, C. M. (2001). A review and assessment of land-use change models: dynamics of space, time, and human choice. USDA Forest Service, Northeastern Research Station, General Technical Report NE-297.
[35] Yang, X., & Lo, C. P. (2003). Modeling urban growth and landscape changes in the Atlanta metropolitan area. International Journal of Geographical Information Science, 17 (5), 463–488.
[36] Dietzel, C., & Clarke, K. (2006). The effect of disaggregating land use categories in cellular automata during

model calibration and forecasting. Computers, Environment and Urban Systems, 30, 78–101.

[37] Kleinbaum, D. G. (1994). Logistic regression: A self-learning text. New York: Springer.

[38] Hosmer, D. W., & Lemeshow, S. (1989). Applied logistic regression. New York: Wiley.

[39] Domencich, T. A., & McFadden, D. (1975). Urban travel demand: behavioral analysis. Amsterdam: North-Holland.

[40] Vermeiren, K., Van Rompaey, A., Loopmans, M., Serwajja, E., & Mukwaya, P. (2012). Urban growth of Kampala, Uganda: Pattern analysis and scenario development. Landscape and Urban Planning, 106(2), 199-206. doi: 10.1016/j.landurbplan.2012.03.006.

[41] Schneider, L., & Pontius, R. G. (2001). Modeling land use change in the Ipswich watershed, Massachusetts, USA. Agriculture, Ecosystems and Environment, 85, 83–94.

[42] JICA (2008). The strategic urban development master plan study for sustainable development of the Greater Cairo region in the Arab Republic of Egypt.The final report summary, volume 1. Cairo, Egypt.

[43] Taher Osman, Takafumi Arima, Prasanna Divigalpitiya. (2013). Dynamism Generated by Alternative Use of Space in the Unplanned Settlements of Greater Cairo Metropolitan region, Proceedings of international symposium of city planning,Sendai,Japan .

[44] [Taher Osman, Takafumi Arima, Prasanna Divigalpitiya.(2014). Tale of Slums in Cairo Region: Describing the actual gap between the unplanned and planned urban growth in the greater Cairo Metropolitan Region, journal of Habitat engineering and urban design Vol 6. No.1, 83-93.

5. Socio-Economic Driving Factors of Urban Sprawl Using AHP method

∗ This chapter is based on the following paper:

Osman, T., Divigalpitiya, P. & Arima, T., 2016. Driving factors of urban sprawl in Giza Governorate of Greater Cairo Metropolitan Region using AHP method. Land Use Policy, 58, pp.21–31. Available at: http://dx.doi.org/10.1016/j.landusepol.2016.07.013.

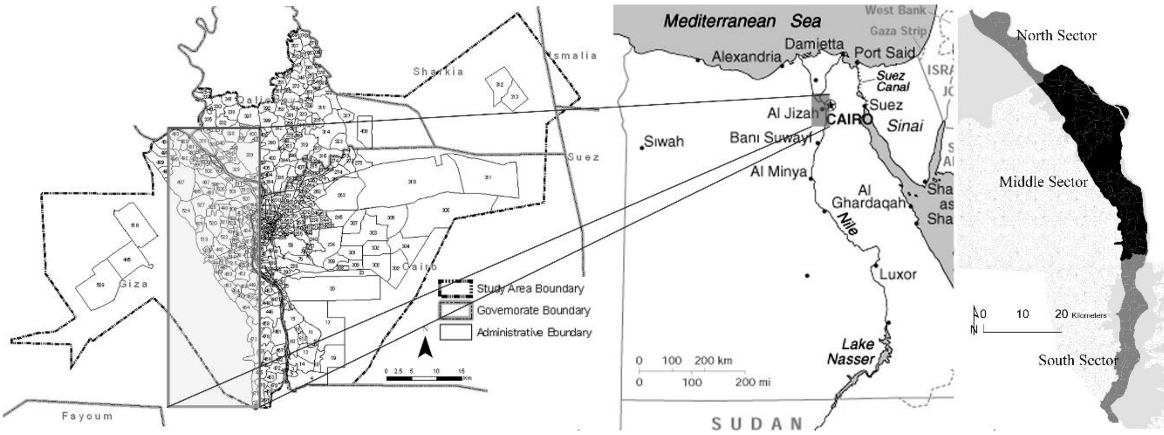
Abstract

Based on questionnaire surveys and the AHP method, this paper determines the driving forces of urban sprawl and analyzes their relative influence on sprawl in the middle, north, and south sectors of Giza Governorate, which is located in the western part of the Greater Cairo Metropolitan Region. Sprawl patterns in the study area were influenced by seven driving forces: geographical characteristics, availability of life facilities, economic incentives, land demand and supply, population increases, administrative functions, and development plans. These forces have varying degrees of influence in each sector. Amongst these forces, economic incentives in the middle sector, population increases in the north sector, and administrative functions in the south sector were the forces most influential in urban sprawl.

Keywords: *Informal urbanization; AHP; driving forces; Slums; urban development; Egypt*

5.1 Introduction

Notwithstanding the government's attempts to contain it, Egypt has experienced rapid urbanization over the past five decades. Official governmental efforts began in 1956 with the introduction of the first urban development plan for the Greater Cairo Metropolitan Region (GCMR). This plan was followed by new plans in 1973, 1982, 1991, and 2006 [1]. The population of the GCMR is around 16–18 million inhabitants, corresponding to nearly a quarter of Egypt's population of 72,798 million inhabitants as of 2006 and about half of the country's urban population. The labor force is growing at over 3.0% per annum due to the considerable youth lump in the population pyramid [1].



(A) Location of Giza within the GCMR [1] (B) Location of Giza within Egypt [2] (C) Giza Sectors

Figure 5.1 Location of the Study Area, Giza Governorate

Urban planning regulations in Egypt conform to a very strict administrative hierarchy that has been completely fixed since the country's conversion from a monarchy to a republic in 1952 [1]. This fixed system regulates the distribution of all official investments for services, infrastructure, and jobs, as well as official data collection for the census, the election system, etc. All development plans must follow this strict bureaucratic system as a fixed parameter. Despite the transformation in the economic system from socialism to capitalism in the 1970s, the administrative system and all related official regulations have remained fixed [3-5]. In Giza Governorate, developmental regulations have continued in the same vein since 1956, when the first urban development plan for the GCMR was introduced; subsequent plans in 1973, 1982, 1991, and 2006 (Table 5.3) have all been based on the same developmental concept of increasing the amount of buildable land to meet growing demand in the GCMR. There has been no real change in political conception.

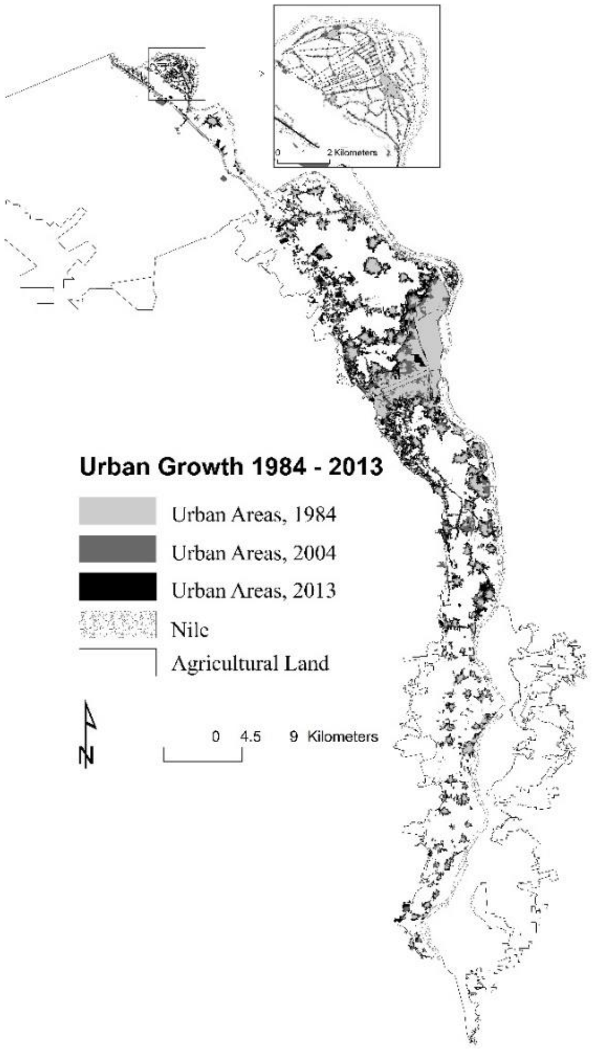


Figure 5.2 Urban areas in Giza in 1984, 2004, and 2013

The switch from socialism to capitalism attracted investment in new industrial and commercial projects. These projects have been concentrated in major cities, particularly the capital, as these places have been the only places that have the infrastructure and are able to satisfy basic requirements for these new activities [3, 5]. With the emergence of these new projects, migrants began to move from rural areas to major cities for job opportunities. Before the 1970s, Egypt did not regulate migration, but fewer people migrated to the GCMR and Alexandria, the two major metropolitan areas in Egypt, in search of work [3, 5].

Young people comprise around 38% of the population of the Giza Governorate compared to 30% nationwide. This is because people from rural areas, particularly Upper Egypt, have migrated to the GCMR for job opportunities. Economic and living conditions throughout Egypt have deteriorated as a result of the political crisis and instability; however, conditions in the GCMR are better than those in other Egyptian governorates. For instance, in 2013, among people between the ages of 18 and 29, the unemployment rate in Giza was 10.8% compared to 30.1% in Sohag Governorate, which is in Upper Egypt and from which the greatest number of migrants originate; it was 29% nationwide. In 2013, the poverty rate in Sohag was 55% compared to 16% in the GCMR [6]. Moreover, the GCMR accounts for 45.2% of total Egyptian production; GCMR workers account for 56% of the total wages in Egypt, compared to 2.2% and 2.3% in the central Upper Egypt region, in which Sohag is located [5,6]. Urban sprawl emerged in the GCMR and in major Egyptian cities in the 1960s. Land development has continued without proper controls; the built environment has grown rapidly, particularly in peripheral areas. All three study sectors in Giza Governorate have witnessed unprecedented urban sprawl rates over the last three decades (Table 5.5).

A study of satellite images estimated that from 1991–1998, the area of urban sprawl in the GCMR grew by 3.4% per annum while the population of sprawl areas grew by 3.2% per annum (or 200,000 people per year) [6]. The Ministry of Planning and German Technical and Financial Cooperation (2004) [7] indicated that since 1980, about 1 million acres of arable land, or 12% of all of the agricultural land in Egypt, have been eroded. El-Hefnawi (2005) [8] estimated that US$46.2 billion worth of arable land has become urban sprawl; urban sprawl on non-arable land is worth US$16.9 billion. Buildings that have been built on arable land as part of urban sprawl are worth US$63.1 billion and comprise 7.9 million units. In Giza Governorate, the urban area grew by 135.34% between 1984 and 2013 (Table 5.5) and by 44.47% between 2004 and 2013; by contrast, growth in the eastern part of the GCMR was only 13% between 2004 and 2013. Urban growth has continued apace without being constrained by urban planning regulations; consequently, between 1984 and 2013, 12,733 ha of high-quality cultivated land was destroyed (Figure 5.2).

Sims (2003) [9], the UNDP (2004) [10], and the Ministry of Planning and German and Technical Financial Cooperation (2004) [7] have indicated that urban sprawl in the GCMR in the past decade has been quite serious and that the tendency toward scattered development and sprawling growth will hinder the Egyptian developmental process if urbanization cannot be kept under control. Recently, the unfavorable influence of urban sprawl has become more evident and the government, in concern, has started to search for solutions in this regard. In 2003, the GCMR had more than 7 million inhabitants living in sprawl areas; 80% lived on privately owned arable land [10, 11]. Urban sprawl in the GCMR can mainly be classified into two categories: (1) urban sprawl on land that was previously arable land and (2) urban sprawl on land that was previously state land [12]. Sprawl has particularly expanded on private arable land; there has been less expansion on publicly owned desert land. The UNDP, 2004 [10] has estimated that by 2025, around 50% of Egypt's urban population will live in sprawl areas.

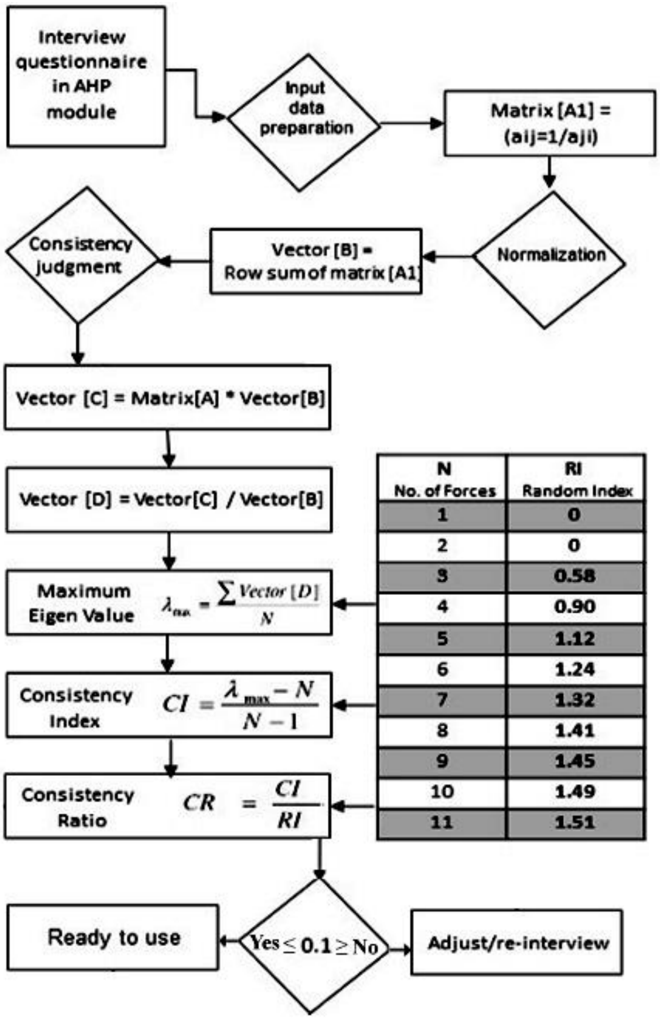


Figure 5.3 Modeling driving forces using the AHP method

The GCMR is located in the Nile Valley, where the flow of the Nile is calm; the valley is bordered on both sides by desert hills (Figure 5.1). Cairo was historically (i.e., pre-1860) limited to higher ground near the eastern hills. The GCMR consists of the entirety of the Cairo Governorate and the urban areas of the Giza Governorate (west of the Nile) and Qalyubia Governorate (north of the Cairo Governorate). Governorates are the major units of municipal administration in Egypt; there is no macro-administrative unit for the GCMR in its entirety. However, authorities in charge of specific services (e.g., authorities for public transport, water, and wastewater) are assigned duties throughout Greater Cairo. For urban planning purposes, the concept of the "Cairo region" has been advanced by the national-level General Organization for Physical Planning (GOPP). Cairo is not only the political capital of Egypt but also its service, social, economic, and administrative hub. For most business and in day-to-day governance, the GCMR is administered by the three governorates and their executive districts.

Barnes et al., 2001 [13], Wilson et al., 2003 [14], Roca et al., 2004 [15], Sudhira and Ramachandra ,2007 [16], and Angel et al.,2007 [17] have indicated that precisely defining urban sprawl for the worldwide context is difficult; however, some researchers have attempted to provide a general definition. Ottensmann,1977 [18] described urban sprawl as the scattering, in inaccessible areas, of new urban developments that are detached from other areas by unoccupied land. Gordon and Richardson, 1997 [19] referred to urban sprawl as "leapfrog development." The Sierra Club,2001 [20] defined urban sprawl as development that is unreliable and typically planned, that occupies green space, and that increases traffic, pollution, and amenity capacity.

Thapa and Murayama,2008 [21] indicated that in order to understand the processes involved in local environmental changes, understanding the knowledge of local experts in the context of decision-making processes is vital. However, investigating growth processes and modeling driving forces by administering questionnaires to local experts remains challenging [22,23] because various drivers play different roles and because growth forces, which are usually correlated, can affect each other directly or indirectly in the urban growth process [24-26]. However, these growth forces are difficult to understand without reference to these relationships.

Thus, conducting research in a variety of regions, Almeida et al., 2003 [27], Bray et al., 2004 [28], Tian et al., 2005 [23], Antrop (2005) [29], and Mottet et al., 2006 [30] have investigated methods to determine relationships, from econometric to probabilistic, among drivers. To rigorously explain the significance of urban growth forces in Kathmandu, Nepal, Thapa and Murayama, 2010 [31] used surveys and questionnaires to understand perceptions among local experts; to their data, they applied the AHP method to obtain quantitative measures.

In this paper, we define "urban sprawl" in the context of Giza Governorate as uncoordinated and unauthorized urban development in the main core areas in the direction of the countryside. Urban sprawl was observed in the periphery of urban areas, along roads connecting the regional centers, and along highways. Urban sprawl areas lack basic life facilities and infrastructure such as for sewage, potable water, schools, hospitals, etc. We define "urban area" as comprising the total extent of urban use in Giza Governorate from 1984–2013, as shown in Figure 5.2 and Table 5.5; the "urban area" includes both areas of planned urban growth and urban sprawl. This being said, in the period 2004–2013, urban sprawl areas constituted around 90% of the total urban area [32, 33]. In the study figures, planned urban areas are not evident as they are extremely tiny and scattered among sprawl areas [33]. JICA, 2008 [1] determined that the north and south sectors would need to be completely off-limits even for planned urban growth. However, sprawl in these areas spread at a breathtaking rate from 2004–2013 (Table 5.5). In the north and south sectors, sprawl rates are 51.48% and 56.60%, respectively. The sprawl rate is 42.50% in the middle sector; apart from a few exceptions of tiny planned growth projects, urban sprawl overwhelmingly comprises the middle sector. To identify planning directions and ensure the sustainable future development of Giza Governorate, driving forces for the unprecedented urban sprawl in this part of the GCMR must be investigated. In this paper, we focus on identifying and weighting the importance of the driving forces of urban sprawl in Giza Governorate.

5.2 Methods and Data

5.2.1 Research Study Sectors of Giza Governorate

Regarding administration, Egyptian municipalities follow an old centralized system that was introduced in the 1960s, when the country became a socialist state. Based on this system, municipal services are provided and information pertaining to, for example, municipal budgets, transportation networks, census data, etc., are organized [3, 5]. In accordance with this system, we divided Giza Governorate, the main study area, into three sectors (Figure 5.1).

Table 5.1 Questionnaire Survey Questions

Round	Date	Questions*
1	April - August2013	What are the driving forces of urban sprawl in the urban area in which you currently live?
2	June 2015	According to their effect, rank the following forces in regard to their increasing effect on urban sprawl on a scale of 1 to 4, where "1" indicates the smallest effect and "4" indicates the largest.

* The original survey was conducted in Arabic and translated into English for this paper.

Table 5.2 Basic Information for the First-Round Questionnaire Survey*

Middle sector		North sector		South sector	
Number of samples	Number of Effective samples	Number of samples	Number of Effective samples	Number of samples	Number of Effective samples
4,080	3,256	420	375	2,820	2,575

* We did not collect information regarding respondent attributes in the first-round survey because such information was not relevant for the purposes of this study; we focused only on querying relevant professional experts.
* The second-round survey included 65 respondents who were top professional experts from the GOPP; 100% of the surveys were valid.

Table 5.3 Urban Development Policies in Giza, 1973–2006 [1-5,and 34-36]

Year	Development Policy
1973	In the establishment of a new city, 6th of October City, it was suggested that a ring road be established around the central urban core and that new urban development be directed into the desert.
1982	To meet the demands of the growing population, two measures were suggested: the establishment of a central urban zone and the establishment of new urban communities in the desert. Regarding the former, a new urban corridor from the central urban area to southern Egypt, crossing the southern sector, was proposed. Regarding the latter, establishing homogenous urban planning sectors with the capacity for 500,000–2 million people was proposed as a way to distribute land use throughout the region.
1991	To address insufficiencies in the 1982 plan, it was proposed that development proceed in the direction of increasing the population of desert cities.
1997	To accommodate 70% of the total increase in population, accelerating the establishment of new urban communities in the desert was proposed; furthermore, completing the ring road and building sub-connections with main arterials within the main urban core was suggested.
2006	To address the failure of previous plans to prevent urban sprawl on agricultural land, redirecting development into the desert was proposed. Agricultural land in the northern and southern sectors was to be considered protected and urban growth was to be limited exclusively to the middle sector.

We separately collected census data and conducted field and questionnaire surveys in each sector. The study results are explained in regard to each sector and are subsequently compared among all sectors. The middle sector is the main urban area in Giza Governorate (Figure 5.4) and is covered by the metropolitan public transportation network. Urban areas in the north and south sectors are considered semi-urbanized areas that commonly exhibit rural characteristics (Figures 5.5 and 5.6). Neither the north nor south sectors are covered by the public transportation system. According to the Egyptian administration system, however, they are a part of the GCMR.

5.2.2 Identifying Driving Forces in Giza Governorate

This paper investigates the driving forces of urban sprawl and weights their influence on urban sprawl in Giza Governorate during the period 1984–2013. We studied the driving forces of urban sprawl in our study area based on a questionnaire survey, which was conducted in two rounds. The first-round survey was aimed at identifying driving forces; it was administered between April 2013 and August 2013 to local experts on the urban environment in Giza. The second-round survey was administered in June 2015 to regional urban experts at the GOPP and was aimed at weighting the importance of the driving forces that had been determined in the first-round questionnaire survey.

In the first-round questionnaire survey, we surveyed local experts among urban planning authorities, real estate property agents, land development and building contractors, employees of public organizations, major property owners, and resident leaders. The first-round questionnaire survey contained open-ended questions; respondents were asked to indicate what they believed were the driving forces of urban sprawl (Table 5.1). Questionnaires were administered in each of the 122 local administrative urban areas; our study investigated 7, 68, and 47 local administrative units in the north, middle, and south sectors of the Giza Governorate, respectively.

This method was utilized for the questionnaire survey because it represents the future of information acquisition from large samples and is comparatively cost-effective [37]. A non-probabilistic purposive sampling method was applied to select respondents for the questionnaire survey. Creswell and Clark, 2007 [38] indicated that purposive sampling is suitable for the selection of respondents with background knowledge about the central phenomenon or key concepts being discussed. A multi-stage sampling logic was used to select resident respondents. At the second stage, participating organizations in each group were stratified into classes based on professions and functions. From each stratum, organizations were chosen indiscriminately and consent to perform the survey was requested by letter. Among administrative organizations, 8 that were part of local municipalities and 10 that were part of the central government of Giza Governorate agreed to participate in the survey.

Figure 5.4 Urban sprawl in the middle sector

Figure 5.5 Urban sprawl in the north sector

Figure 5.6 Urban sprawl in the south sector

For the first-round survey, questionnaires were sent to and collected from governmental employees through their head offices. For respondents who did not work for the government, questionnaires were delivered to and collected from their work addresses by hand. A total of 7,320 questionnaires were distributed; 420, 4,080, and 2,820 questionnaires were distributed in the north, middle, and south sectors, respectively (Table 5.5). In the north sector, 398 surveys were collected. Out of the 398 collected questionnaires, 23 were excluded for incompleteness; 375 valid questionnaires were obtained for a return rate of 89.2%.

In the middle sector, 3,631 surveys were collected. Out of the 3,631 collected questionnaires, 187 were excluded for incompleteness; 3,256 valid questionnaires were obtained for a return rate of 79.8%. In the south sector, 2,654 surveys were collected (Table 5.2). Out of the 2,654 collected questionnaires, 79 were excluded for incompleteness; 2,575 valid questionnaires were obtained for a return rate of 91.3%. The sample size was considered appropriate and reasonable. Taylor, 2012 [39] indicated that when the target of sampling is uncertain, 300–500 samples is workable as long as the survey is representative of at least 55% of the valid samples. Responses from the first-round questionnaire survey were collected and arranged by study sector—north, middle, or south. We tabulated how many times each driving force was suggested (Table 5.5). Subsequently, we used this list for the second-round questionnaire survey.

Table 5.4 Representation and synthesis of Sprawl Forces in Giza

Synthesis	Representation characteristics
Administrative functions	Official plans for investments in services, infrastructure, and jobs for various areas are determined according to those areas' rank in the Egyptian hierarchy of administrative units—cities are given the most resources, followed by mother villages and villages.
Population increases	Resulting from both natural increase and migration, from 1984–2013, urban areas saw population increases. This created a demand for more buildable land and services and, ultimately, facilitated changes in land use.
Economic incentives	The GCMR is Egypt's major economic hub. Hence, certain parts of the GCMR are attractive for offering lucrative jobs and business opportunities in tourism, finance, industry, education, health, wholesaling, and retail.
Availability of life facilities	Certain urban areas are attractive for providing basic services, such as services in regard to transportation, electricity, education, drinking water, health, commerce, waste disposal, open spaces, and recreation.
Development plans	Official governmental plans have attempted to direct the demand for buildable land to specific locations based on regional development policies.
Geographical characteristics	Topography, slopes, and soil have an effect on the direction taken by urban sprawl.
Land demand and supply	Land market mechanisms play a role in demand and supply: land prices, brokers, and real estate developers direct urban sprawl to specific locations.

To extract items for the second-round survey from the answers obtained in the first-round survey, we grouped individual respondent answer sheets obtained from the 122 study areas into their relevant sectors—north, middle, and south. Within each sector, we grouped respondent answers to formulate a concrete synthesis (Table 5.4). We summarized respondent answers based on different synonyms in order to synthesize seven major driving forces; respondent answers that could not be categorized under one of the seven major driving forces were categorized as "other" and were excluded from the second-round survey. We eliminated forces categorized as "other" (Table 5.5) from the second-round survey as they were irrelevant to the major purpose of our study, namely, determining the most significant sprawl forces for management by urban planners in order to direct future urban development in the GCMR. Miscellaneous eliminated answers accounted for less than 5% of the total answers from middle and south sectors and 6.93% of the total answers from the northern sector. We prepared final sheets for each study sector; these sheets included the driving forces that respondents were to be surveyed in regard to in the second-round survey.

Moreover, for the second-round survey, we determined 65 regional urban experts from the GOPP with five or more years of experience in the field. Questionnaire survey forms were delivered to and retrieved from their offices at the GOPP by hand. Lists of driving forces that had been identified in the first-round survey were provided on the questionnaires; a distinct list was provided to each of the north, middle, and south sectors. Respondents had five business days to submit their answers; 100% of the questionnaires were valid. We employed closed-ended questions. On each of the lists, which differed by sector, respondents were requested to weight the driving factors on a scale of 1 to 4. We applied the AHP model (Figure 5.3) to the output of the second-round survey in order to calculate weights for the driving forces of urban sprawl that had been suggested in the first-round survey in each study sector (Table 5.5).

The AHP is a methodology for examining and resolving synthesis-resolution issues by organizing them into a hierarchical framework [18]. The AHP procedure is applied for rating a set of choices or for identifying the best in a set of choices. Rating is performed with regard to an inclusive aim, which is distributed into a set of standards. The AHP procedure involves the four major steps of calculating the AHP hierarchy pairwise comparison, differentiation, calculating consistency ratios, and calculating the definitive significance. Thapa and Murayama, 2010 [31] administered a set of questionnaires to local residents, researchers, urban and regional planners, and academics to observe changes in the surrounding environment and the causes for these changes from different perspectives; their intention was to obtain key information for identifying the driving forces of urban growth in the last decade in Kathmandu, Nepal. They used the AHP framework to analyze respondent answers and grasp the relative importance of each driving force with respect to the others. In this research, a four level hierarchy of aims, objectives, attributes, and choices was investigated to depict the spatial AHP system.

5.3 Results

Urban sprawl in Giza during the period 1984–2013 reached unprecedented levels in all three study sectors, as well as in comparison with the entirety of the GCMR (Table 5.5). In the north sector, the urban area increased from 187 to 588 ha during the period 1984–2004; the average annual urban growth and population growth rates were 10.72% and 2.3%, respectively. From 2004–2013, the urban area increased from 588 to 891 ha; the average annual urban growth and population growth rates were 5.7% and 1.9%, respectively. In the middle sector, the urban area increased from 8,354 to 12,962 ha during the period 1984–2004.

The average annual urban growth and population growth rates were 2.76% and 2.15%, respectively. From 2004–2013, the urban area increased to 18,471 ha; the average annual urban growth and population growth rates were 4.7% and 1.83%, respectively. In the south sector, the urban area increased from 861 to 1,771 ha during the period 1984–2004. The average annual urban growth and population growth rates were 5.28% and 2.25%, respectively. From 2004–2013, the urban area increased to 2,773 ha; the average annual urban growth and population growth rates were 6.3% and 1.95%, respectively. Over the period 2004–2013, the total urban area increased by 51.5% in the north sector, 42.5% in the middle sector, and 56.6% in the southern sector; in the entirety of the study area, the average increase was 44.47% (Figure 5.2).

Table 5.5 Rates of Urban and Population Growth in the Giza Sectors in 1984, 2004, and 2013*

Study sector	1984		2004		2013	
	Urban area (ha)	Population	Urban area (ha)	Population	Urban area (ha)	Population
North	187.37	51,240	588.26	95,323	891.10	111,814
Middle	8,354.80	1,807,909	12,962.04	3,363,552	18,470.98	3,945,166
South	861.70	237,512	1,770.80	441,883	2,773.10	518,292

*Urban growth areas were classified based on Landsat satellite images (USGS) [40].

* * Population numbers were identified from CAPMAS [6].

5.3.1 Identifying the Driving Forces of Urban Sprawl Based on the Questionnaire Survey

A. Driving Forces in the Middle Sector Zone of Giza

Table 5.6 Driving Forces Indicated in Questionnaire Responses and Number of Mentions by Sector

Answers (Major forces)	Middle sector		North sector		South sector	
	Number of mentions	Percentages (%)	Number of mentions	Percentages (%)	Number of mentions	Percentages (%)
Administrative functions	2,795	85.84	349	93.06	2,539	98.60
Population increases	3,187	97.88	368	98.13	2,386	92.66
Economic incentives	3,256	100.00	341	90.93	2,052	79.68
Availability of life facilities	3,094	95.02	317	84.53	1,843	71.57
Development plans	2,521	77.42	311	82.93	1,843	71.57
Geographical characteristics	2,043	62.74	301	80.26	2,109	81.90
Land demand and supply	2,647	81.29	324	86.4	2,214	85.98
Others	153	4.69	26	6.93	107	4.15
Total number of valid responses	3,256		375		2,575	

In the first-round questionnaire survey, 100% of valid responses indicated economic incentives as a driving force for urban sprawl; 97.88% of valid responses in the middle sector identified population increases as a driving force of urban sprawl. Availability of life facilities was identified as a driving force of urban sprawl in 95.02% of valid responses. In addition, 85.84% of valid responses indicated that administrative functions are the main driving force in urban sprawl in the middle sector. Land demand and supply were identified as a driving force in 81.29% of valid responses and development plans were identified as a driving force in 77.42% of valid responses. Lastly, geographical characteristics were identified as a driving force in 62.74% of valid responses from the middle sector (Table 5.6).

B. Driving Forces in the Northern Sector Zone of Giza

Among the valid responses, 98.13% indicated population increases as the main driving force in urban sprawl; 93.06% of valid responses indicated administrative functions in urban areas under the official governmental classification system (city, mother village, or small village [1,3] as a driving force. Economic incentives were mentioned in 90.93% of valid responses. In this sector, 86.4% of responses indicated land demand and supply, which are affected by land market conditions, land speculation, and land prices, as a driving force. Availability of life facilities was indicated as a driving force in 84.53% of valid responses. Development plans, which are official governmental plans for new buildable land, were identified as a driving force in 82.93% of responses. Geographical characteristics were identified as a driving force in 80.26% of valid responses from this sector (Table 5.6).

C. Driving Forces in the Southern Sector Zone of Giza

Administrative functions were identified as a driving force by 98.60% of respondents in this sector; economic incentives came second with 97.88%. Population increases were identified in 92.66% of the valid responses as a driving force of urban sprawl. Land demand and supply were identified as a driving force in 85.98% of valid responses from the south sector. Geographical characteristics were identified as a driving force in 81.90% of valid responses. Availability of life facilities was identified as a driving force in 71.57% of valid samples. Development plans were indicated as a driving force in 71.57% of responses. While other forces were identified as driving sprawl in all three study sectors, these forces were excluded from the results because they were only indicated as driving forces by a small number of valid respondents. "Other forces" included driving forces that were related to religion, society, culture, security, politics, and the media (Table 5.6).

5.3.2 Identifying the Weights of the Urban Sprawl Driving Forces by AHP

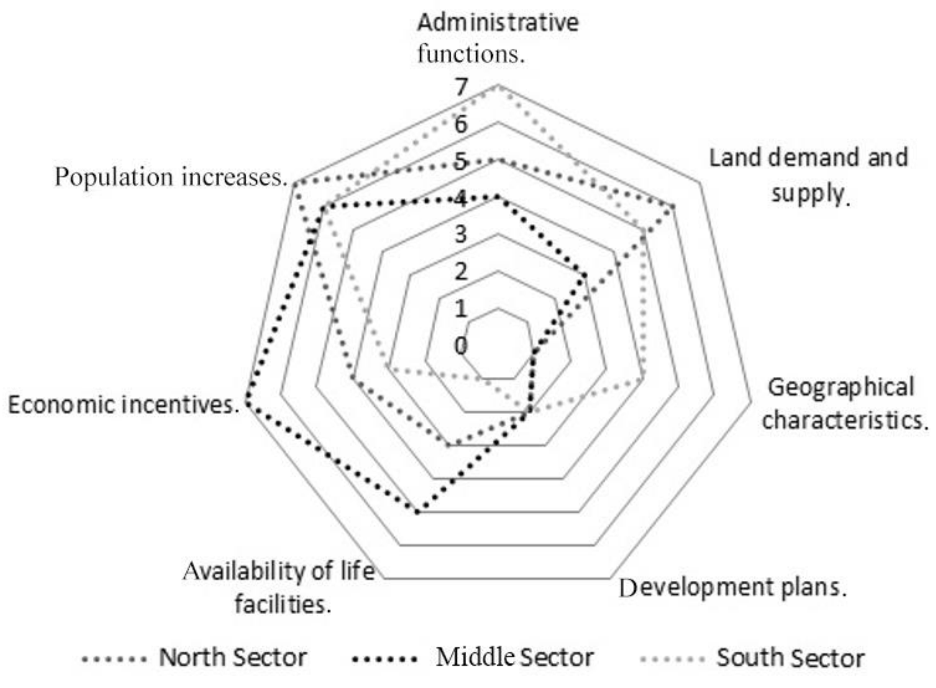


Figure 5.7 Driving Forces: Impact Rankings

Second, we identified weights for each of the driving forces of urban sprawl by using the AHP method. The forecasted outputs in the three study sectors were accomplished with the consistency ratios (CR) of 0.007, 0.009, and 0.006 for the middle, north, and south sectors, respectively. These values were extremely good in regard to the maximum reasonable (≤ 0.1) domain [41]. Definitive scores for the driving forces were scaled to 0–100 for simpler preformation. The outputs are explained by sector. The driving forces were sorted from 1 to 7 (from smallest to largest influence) and are presented in a radar chart (Figure 5.7) to illustrate the correlation among the driving forces in urban sprawl in the Cairo Region. Significant divergences among the three study sectors and among the forces were observed.

Table 5.7 Driving Forces Indicated in Questionnaire Responses and Number of Mentions: The Middle Sector

Answers (Major forces)	Questionnaire respondent scores				Weight from AHP (%)
	1	2	3	4	
Administrative functions	12	14	12	27	14.53
Population increases	7	7	10	41	16.98
Economic incentives	2	5	5	53	18.88
Availability of life facilities	8	11	10	36	16.11
Development plans	26	18	10	11	10.74
Geographical characteristics	25	27	7	6	9.79
Land demand and supply	16	15	18	16	12.95

Table 5.8 Driving Forces Indicated in Questionnaire Responses and Number of Mentions: The North Sector

Answers (Major forces)	Questionnaire respondent scores				Weight from AHP (%)
	1	2	3	4	
Administrative functions	4	10	14	37	18.10
Population increases	1	6	9	49	19.97
Economic incentives	5	14	14	32	17.17
Availability of life facilities	10	12	22	21	15.57
Development plans	49	16	0	0	6.85
Geographical characteristics	54	11	0	0	6.43
Land demand and supply	8	18	12	27	15.91

Table 5.9 Driving Forces Indicated in Questionnaire Responses and Number of Mentions: The South Sector

Answers (Major forces)	Questionnaire respondent scores				Weight from AHP (%)
	1	2	3	4	
Administrative functions	3	2	11	49	18.42
Population increases	4	9	14	38	16.86
Economic incentives	6	15	18	26	15.14
Availability of life facilities	18	14	13	20	12.88
Development plans	59	6	0	0	5.54
Geographical characteristics	12	8	15	30	15.07
Land demand and supply	8	7	16	34	16.08

Economic incentives in the middle sector, population increases in the north sector, and administrative functions in the south sector were the most influential forces in the alteration of the region, which was originally uniform cultivated land. Despite the similarity in these regions, driving forces varied in significance in the three sectors. At this stage, three lists of suggested driving forces were formulated. Each driving force was weighted based on survey responses. We observed commonalities in questionnaire responses from the three study sectors. The seven major driving forces were common to all three sectors but differed in significance.

5.4 Analysis and Discussion

GCMR planning policies from 1956 to 2006 (Table 5.3) were formulated for the purpose of adequately expanding the urban area to meet growing demand in regard to various activities, particularly housing [1-5,34-36,42,43]. However, urban sprawl was not a problem for urban planners until the 1983 plan, which launched the ring road project. The ring road project did not envisage the negative impact on agricultural land or the threat of urban sprawl [34, 42, and 43]. Consequently, there was an astonishing acceleration in the urban sprawl rate, which had grown to 3.4% annually by 1991[6].

In addition, the 1991 plan ignored informal population growth, as real population growth could not be identified based on the census [9, 32]. The direction of growth in reality led to illogical plans that completely failed to manage urban sprawl into agricultural land (Table 5.5). The last policy, in 2006, prioritized the protection of agricultural land but failed to treat this problem in a proper way—if driving forces of growth had been identified, they could have been effectively dealt and growth could have been effectively directed to retain buildable land to satisfy the needs of Cairo residents. As a result of this failure, the urban growth rate was increased despite the fact that protections had theoretically been included in the 2006 policy (Table 5.5 and Figure 5. 2).

In the middle sector, economic incentives were indicated as the most influential driving force (Figure. 7), though it ranked only as the third- and fourth-most influential driving force in the northern and southern sectors, respectively. This was because the middle sector is Giza Governorate's major commercial and governmental base [1, 43]. The middle sector is congested and has limited suitable land for development [7, 33, and 43]. Buildable land is only affordable for a handful of residents and commercial organizations [12, 43]. Much of the land in the area is being converted for business establishments or for high-end housing [1, 12, and 34]. These developments have generated various types of jobs that have attracted a substantial number of migrants; this has strongly contributed to the increase in population [1, 32, and 35]. By contrast, geographical characteristics and development plans were considered relatively unimportant in this sector.

Regarding the latter, this may due to the fact that cultivated land in the middle sector is already scarce; development is restricted to urban renewal schemes. Geographical characteristics were not considered a driving force in the middle sector because it has a high percentage of flat terrain and is already largely developed [33, 43]. Businessmen and investors are progressively interested to exploit even though physiographic restrictions forced them to exploit land at a higher cost in the first stage. Since there is higher availability of service facilities, functional difficulties are not the main limitation in the middle and north sectors. In addition to that, availability of life facilities was ranked as the third-most influential driving force in the middle sector. This is because the sector has excellent roads, hospitals, parks, and educational organizations [1, 34, and 43]. The head offices of the major governmental foundations are located in the area [44].

Administrative functions were ranked first in the south sector, second in the north sector, and fourth in the middle sector. This is reflective of the fact that urban areas are located in cities, mother villages, and villages; this has increased the rate of urban sprawl, particularly in south and north sectors. Annual budgets for upgrading local municipalities are determined by the government in accordance with the Egyptian administrative system [1, 3, and 5]. Cities are afforded the largest share of the budget; regardless of other factors, mother villages are given a larger share of the budget than are small villages. This has an extremely strong effect in the south and north sectors, which have some of the urban areas that are most in need of upgrading in all of Giza [5,9,10].

In the north sector, it was indicated that the most influential driving force in urban sprawl is population increases (Figure 5.7). Some indigenous residents are actively maintaining their ancestral land [1, 35]. Consequently, the population has increased consistently. Moreover, investors are attracted to the north sector for residential development. Some new high-class residential areas in Egypt are emerging in this area [1, 9, and 12]. With increases in the population (Table 5.5), the demand for housing has escalated accordingly. In the middle and south sectors, population increases were indicated as the second-most influential driving force; compared with the north sector, population increases were considered less influential as a driving force in the south and middle sectors.

In the north sector, there are both urban and rural lifestyles [1, 9, and 12]. Consequently, it contains high-, low-, and mixed-income residential areas. Land prices in the north sector are relatively moderate compared with the middle sector [1, 9, and 12]. In the south sector (Figure 5.7), geographical characteristics were ranked as the fourth most influential driving force; this was relatively high compared to in other sectors (Tables 5.7, 5.8, and 5.9). The south sector has rich soil and water; this has attracted numerous mercantile producers [1, 3, and 35]. The soil in the area is good for brick manufacturing [1, 3, and 35]. Perhaps it is because of these features that geographical characteristics were ranked higher in regard to the south sector than in the other sectors. Economic incentives, availability of life facilities, and development plans ranked relatively low compared to the other driving forces.

Apart from its quarry and brick industry, the south sector has few other economic activities [1, 3, and 35]. In light of Egyptian standards for services and urban planning, residents of the south sector have minimal access to education, public transportation, and other facilities [1, 34]. Residents who require services and facilities must travel to the north or middle sectors. Given that life facilities in the sector are few, their presence has not exerted a considerable influence on the sector's urbanization

[1,3,34,35]. At present, certain planned residential zones are being developed as private projects of local contractors, but they are not expected to have a significant impact. Figure 5.7 explains the functions of the driving forces and how they function in the three sectors in the conversion of cultivated land. Population increases were ranked as the most influential driving force in the north sector—more influential than geographical characteristics.

By contrast, geographical characteristics in the south sector were as influential as land demand and supply in the middle sector. Driving forces of equal intensity could also be identified within study regions—for instance, in the south sector, availability of life facilities and development plans were driving forces of the same intensity. It is evident that driving forces exhibit various characteristic functions in influencing the conversion of cultivated land in Giza Governorate; this is due to the different human–nature relationships implied at various stages of sprawl. This investigation showed that development plans have had an insubstantial influence on the informal conversion of agriculture land to urban use. Governmental urban policies over the past four decades have been ineffective, as other researchers have asserted [32, 44]. Many rural migrants were identified as living in these areas.

Among the sectors, land demand and supply was ranked highest in the south sector (Figure 5.7). Fieldwork determined that local residents, land speculators, and real estate developers are active in converting agricultural land for urban use. Real estate contractors acquire land from one or more local residents, depending on the plot size. This land is sold—converted for residential areas or at a higher price [35, 44, and 45]. After a client buys land in a specific zone, a social network becomes active [35, 44, and 45]. For new developments and land trades, land in the south sector is cheaper. Land speculators and local people are extremely active in land trades in rural areas and in the north sector. This may explain why in these areas, land demand and supply were ranked relatively higher in these areas compared with in the middle sector (Figure 5.7).

5.5 Conclusion

This paper's most significant result is in its discovery that development plans are of low significance as a driving force in urban extension. By contrast, in all three study sectors, population increases were indicated as having high significance. Moreover, the results highlighted significant differences between the study sectors in regard to driving forces in urban sprawl. For instance, in the middle sector, economic incentives and the availability of life facilities were the most important driving forces; in the south sector, administrative functions and land demand and supply were the most significant driving forces; and in the north sector, population increases and administrative functions were the most active driving forces.

The study results can be used to determine effective urban management tools that can help to manage future urban expansion in Giza Governorate and similar Egyptian cities. Our study results highlighted significant differences among the study sectors in regard to internal urban sprawl drivers; these results may be used to ensure that tailored urban plans for each sector are formulated as a substitute for the current plans, which have ignored such differences and have treated the entire governorate as a single unit. This has led to a vacuum of effective plans for directing urban expansion in Giza. Moreover, adjusting administration functions by changing the rank of urban areas (city, mother village, and village) could be an effective tool to adjust urban sprawl, particularly in the south and north sectors.

Urban development planning can prevail over the existing bubbles generated by the socialist era, which are now useless in directing urban expansion in Giza Governorate. As a driving force, development plans may become more efficacious compared to over the last decade by taking into consideration the differences among the study sectors and using the urban sprawl drivers to formulate detailed plans to enforce planning policies. In future research, it is highly essential that the driving forces determined in this study are converted to spatial indices that could be used as real planning tools to enforce future development in the GCMR.

References

[1] JICA (2008). Strategic urban development master plan study for sustainable development of the Greater Cairo region in the Arabic Republic of Egypt. Final report summary, Volume 1. Cairo, Egypt.

[2] Central Intelligence Agency World Factbook. Retrieved December 14, 2015 from https://www.cia.gov/index.html.

[3] National Urban Policy Study (1981). PADCO, Inc. and ECG. Egypt.

[4] M. M. El Araby (2003). The role of the state in managing urban land supply and prices in Egypt. Habitat International, 27 (2003), pp. 429–458.

[5] General Organization of Physical Planning (2010). Cairo Future Vision 2050: Within a National Vision of Egypt. Cities, 18 (3) (2001), pp. 135– 149.

[6] Central Agency for Population, Mobilization and Statistics (2006). General Census of Population, Housing and Buildings 2006. Central Agency for Population, Mobilization and Statistics, Cairo, Egypt.

[7] Ministry of Planning and German Technical and Financial Cooperation, 2004. New Practice of Participatory Local-Development in Egypt's Urban Areas. Egypt.

[8] A. El-Hefnawi (2005). Protecting agricultural land from urbanization or managing the conflict between informal urban growth while meeting the demands of the communities. Third Urban Research Symposium on Land Development, Urban Policy, and Poverty Reduction. World Bank Institute of Applied Economic Research, Brasilia, Brazil.

[9] D. Sims (2003). The case of Cairo, Egypt. In: The challenge of slums: Global report on human settlements 2003. Earthscan, London.

[10] UNDP/INP (2004). Egypt human development report 2004: Choosing decentralization for good governance. UNDP/Institute of National Planning, Cairo, Egypt.

[11] Taher Osman, Takafumi Arima, and Prasanna Divigalpitiya. The tale of slums in Cairo region: Describing the actual gap between the unplanned and planned urban growth in the Greater Cairo Metropolitan Region. Journal of Habitat Engineering and Urban Design, 6 (1) (2014b), pp. 83–93.

[12] Taher Osman, Takafumi Arima, and Prasanna Divigalpitiya (2014a). Pseudo urbanization in Cairo region: Measuring urban sprawl with geospatial indices. In: Proceedings of the IASUR Conference. IASUR, Tokyo, Japan.
[13] K.B. Barnes, J.M. Morgan III, M.C. Roberge, and S. Lowe (2001). Sprawl development: Its patterns, consequences, and measurement. Retrieved from: http://chesapeake.towson.edu/landscape/urbansprawl/download/Sprawl_white_paper.pdf.
[14] E. H. Wilson, J. D. Hurd, D. L. Civco, S. Prisloe, and C. Arnold. Development of a geospatial model to quantify, describe and map urban growth. Remote Sensing of Environment, 86 (3) (2003), pp. 275–285.
[15] J. Roca, M. C. Burnsa, and J. M. Carreras (2004). Monitoring urban sprawl around Barcelona's metropolitan area with the aid of satellite imagery. In: Proceedings of Geo-Imagery Bridging Continents. 20th ISPRS Congress, Istanbul, Turkey.
[16] H.S. Sudhira and T. V. Ramachandra (2007). Characterizing urban sprawl from remote sensing data and using landscape metrics. In: Proceedings of the 10th International Conference on Computers in Urban Planning and Urban Management. CUPUM, Iguassu Falls, Brazil. Retrieved from: http://eprints.iisc.ernet.in/11834/.
[17] S. Angel, J. Parent, and D. Civco (2007). Urban sprawl metrics: an analysis of global urban expansion using GIS. In: Proceedings of the ASPRS 2007 Annual Conference. Retrieved from: http://clear.uconn.edu/publications/research/tech_papers/Angel_et_al_ASPRS2007.pdf.
[18] J. R. Ottensmann. (1977). Urban sprawl, land values and the density of development. Land Economics, 53 (4), pp. 389–400.
[19] P. Gordon and H. W. Richardson (1997). Are compact cities a desirable planning goal? Journal of the American Planning Association, 63 (1), pp. 95–106.
[20] Sierra Club (2001). Stop sprawl: New research on population, suburban sprawl, and smart growth. Retrieved from: www.sierraclub.org/sprawl/.
[21] R. B. Thapa, Y. Murayama, and S. Ale. (2008). Kathmandu. Cities, 25, pp. 45–57.
[22] N. Schneeberger, M. Burgi, A. M. Hersperger, and K. C. Ewald. (2007). Driving forces and rates of landscape change as a promising combination for landscape change research and application on the northern fringe of the Swiss Alps. Land Use Policy, 24, pp. 349–361.
[23] G. Tian, J. Liu, Y. Xie, Z. Yang, D. Zhuang, and Z. Niu. (2005). Analysis of spatio-temporal dynamic pattern and driving forces of urban land in China in 1990s using TM images and GIS. Cities, 22, pp. 400–410.
[24] D. B. Bray, E. A. Ellis, N. Armijo-Canto, and C. T. Beck. (2004). The institutional drivers of sustainable landscapes: A case study of the "Mayan Zone" in Quintana Roo, Mexico. Land Use Policy, 21, pp. 333–346.
[25] P. H. Verburg, J. Ritsema van Eck, T. de Nijs, P. Schot, and M. Dijst (2004). Determinants of land-use change patterns in the Netherlands. Environment and Planning B, 31, pp. 125–150.
[26] S. Zang and X. Huang (2006). An aggregated multivariate regression land-use model and its application to land-use change processes in the Daqing region (northeast China). Ecological Modelling, 193, pp. 503–516.
[27] C. M. Almeida, M. Batty, A. M. V. Monteiro, G. Camara, B. S. Soares-Filho, G. C. Cerqueira, et al. (2003). Stochastic cellular automata modeling of urban land use dynamics: empirical development and estimation. Computers, Environment and Urban Systems, 27, pp. 481–509.
[28] D. B. Bray, E. A. Ellis, N. Armijo-Canto, and C. T. Beck (2004). The institutional drivers of sustainable landscapes: A case study of the "Mayan Zone" in Quintana Roo, Mexico. Land Use Policy, 21, 333–346.
[29] M. Antrop. (2005). Why landscapes of the past are important for the future. Landscape and Urban Planning, 70, pp. 21–34.
[30] A. Mottet, S. Ladet, N. Coque, and A. Gibon (2006). Agricultural landuse change and its drivers in mountain landscapes: A case study in the Pyrenees. Agriculture, Ecosystems and Environment, 114, pp. 296–310.
[31] R. B. Thapa and Y. Murayama (2010). Drivers of urban growth in the Kathmandu valley, Nepal: Examining the efficacy of the analytic hierarchy process. Applied Geography, 30 (1), pp. 70–83. Retrieved from: http://www.sciencedirect.com/science/article/pii/S014362280900068X.
[32] D. Sims, M. Sejoume, and M. El Shorbagi (2003). The case of Cairo, Egypt. In: Understanding slums: Case studies for the global report 2003, the case of Cairo, Egypt.
[33] Taher Osman, Prasanna Divigalpitiya,Takafumi Arima, Modeling urban growth scenarios in Cairo Metropolitan Region 2050, Proceedings of the 14th International Conference of Computers in Urban planning and Urban management CUPUM 2015, Massachusetts institute of technology MIT, Boston, USA.

[34] Taher Osman, Prasanna Divigalpitiya, Takafumi Arima. Effect of Governmental Housing Regulations on the Egyptian housing market: Focusing on Greater Cairo Metropolitan Region. Journal of Architecture and Urban Design, Kyushu University, 28 (2015), pp. 1–9.
[35] General Organization of Physical Planning (2005). Project of development plans for Egyptian villages. Cairo, Egypt.
[36] 36) Keith Sutton and Wael Fahmi (2001). Cairo's urban growth and strategic master plans in the light of Egypt's 1996 population census. Cities, 18 (3) (2001), pp. 135-149.
[37] D. J. Cohen and B. J. Crabtree (2006). Qualitative research guidelines project. Retrieved from: http://www.qualres.org/.
[38] J. W. Creswell and V. L. Plano Clark (2007). Designing and conducting mixed methods research. Sage, Thousand Oaks, CA.
[39] I. Taylor (2012). Survey sample sizes: How many respondents do you really need? Retrieved from: http://blog.questionpro.com/author/thirdforce/.
[40] US Geological Survey. Retrieved from: http://www.usgs.gov/.
[41] T. L. Saaty (1980). The analytic hierarchy process. McGraw-Hill, New York.
[42] M. El-Batran and C. Arandel. A shelter of their own: Informal settlement expansion in Greater Cairo and government responses. Environment and Urbanization, 10 (1) (1998).
[43] Mohamed Mohamed Amin Abd-Allah (2007). Modeling urban dynamics using geographic information systems, remote sensing, and urban growth models. PhD thesis, Cairo University, Faculty of Engineering.
[44] Taher Osman, Takafumi Arima, and Prasanna Divigalpitiya (2013). Dynamism generated by alternative use of space in the unplanned settlements of Greater Cairo Metropolitan Region. In: Proceedings of the 2013 International Symposium on City Planning. ISCP, Sendai, Japan.
[45] Taher Osman, Prasanna Divigalpitiya Takafumi Arima, 2016. Measuring Urban Sprawl Patterns in Greater Cairo Metropolitan Region. Journal of the Indian Society of Remote Sensing. Available at: http://link.springer.com/10.1007/s12524-015-0489-6.

6. Modeling Land-use change scenarios in 2035 in Giza area by using integrating Markov chain, cellular automata and logistic regression models

∗ This chapter is based on the following paper:

Osman, T., Divigalpitiya, P., Salem, M., Omrani H., Tayyebi A. & Arima, T.,2016.Simulation of Land-use Change Scenarios By integrating Markov chain, cellular automata and logistic regression Models.Proceedings of the 2016 International conference of sustainable mega projects,British University in Egypt, pp. 1-8.

Abstract

This study simulated urban sprawl and their risks on agricultural lands shrinkage in the greater Cairo metropolitan region (GCMR). An integrated model based on Markov chain (MC), cellular automata (CA), logistic regression (LR), called MC-CA-LR after here, built to model future urban scenarios. Historical land use data generated using Landsat TM/ETM images in 1984, 2004 and 2013. Scenario modeling used to better understand the relationship between urban dynamics and their risks on agriculture loss. Three urban development scenarios, namely, historical growth trend (HGT), compact growth (CG) and growth as planned officially (GPO) designed and transplanted into the MC-CA-LR model through the parameter self-modification method. The simulation results were compared with land use data in 2013 to assess the validity of simulations. The MC method provided the best results according to the validation based on the kappa index of agreement. The quantitative analysis results showed that in the period of the past nine years, the urban sprawl primarily spreads in whole study area. The simulations show that under the GPO scenarios the urban sprawl will continue emerging everywhere in the metropolitan region, while under the CG scenario the urban sprawl will concentrate only around major urban areas or major road networks, respectively. Moreover, the experiment results demonstrated that the CG scenario was more effective in meeting the goal of agricultural lands protection and sustainable development for the GCMR. The results of this study demonstrated that the urban sprawl models provide a better understanding of the current and future land use change dynamics and provide a framework for decision makers to increase sustainability in landscape.

Keywords: Urban scenarios; land use change; logistic regression; Markov chain; cellular automata; agriculture protection.

6.1 Introduction

Over last two decades, the outskirts of the metropolitan regions have been formed by urban sprawl [1, 2]. These dynamics result in urban sprawl, as dispersed business uses strip development with large spreads of single use development with low density, poor accessibility, and lack of public open space [3]. To counteract such development tendencies and guarantee sustainability, urban planners have to meet a strong challenge with respect to urban planning and land use management due to the dominant high dynamic urban sprawl. Thus, land use change (LUC) analysis has received significant consideration from urban research scholars. An important necessity for better understanding the trend of LUC is data on current land use types and changes over time [4, 5]. Important contributions in this area have been related to the progress of GIS and remote sensing [6, 7], which have been utilized to model LUC [8].

Urban expansion monitoring and modelling has been an important theme in academia to improve and adjust theories of urban morphology [13-15]. There is still an absence of combination between most dynamic simulation models and socioeconomic drivers. Tools such as city evolution trees presents a new method to examine urban sprawl on a global scale [16]. The agent-based models shows the latest technique to model the influence of the behavior of individuals on LUC [17, 18]. Alternative urban modelling methods rely on a set of fixed assumptions and methods [19], such as cellular automata (CA) [20-22], Markov chain (MC) models [23-25], logistic regression (LR) model, rule-based models [26], learning algorithms [27]. A variety of studies have been conducted in LUC science and each of these studies showed tried to show advantages and disadvantages of each LUC model.

Due to restrictions of each individual modelling method, this study integrated thee models with each other, called MC-CA-LR after here, to take advantage of the best characteristic of each model. MC can compute the amount of LUC and identify the structural utilization; however, MC are spatially non-explicit since they only compute the probabilities of land use transitions and the quantity of change [32]. CA models avoid this restraint of MC based on predefined site-specific instructions to simulate land use transitions [12, 33]; however, CA models do not the capability to determine the quantity of LUC between two times. Thus, we integrated MC with CA to simulate location of LUC as well as quantity of LUC between two times. In addition, model calibration in CA consists of determining a set of transition rules. Extensive search strategies are required to explore appropriate combinations of transition rules and determination of transition rules is even more complex when additional spatial variables are considered. LR models avoid this restraint of CA which significantly reduce the model calibration time. Thus, we coupled CA with LR to simulate non-linear LUC patterns in a reasonable time spans as well as high accuracy. Though, the combined model could not consider LR in identifying the driving factors of LUC.

The alteration of rural land to urban uses did numerous negative influences on ecosystem structure, dynamics, and function [39-41]. Deteriorating sprawl circumstances of crowding, inadequate infrastructure, housing shortages, and increasing threats of urban climatological and ecological problems require a consistent observing of urban sprawl dynamics [42]. While by 2050 population of entire world is expected to increase by 38%, urbanization is one of key factors of losing agriculture lands. This fact is even more controversial for metropolitan areas since big cities have more residents. Thus, it is necessary to quantify amount of agriculture loss due to urbanization especially around metropolitan areas. Socio-economic status and population growth are major factors of agriculture loss around metropolitan areas. That fact has direct influences on land use and add a constant stress on the environment. Most qualitative, qualitative, and semi quantitative analyses have concentrated on human activity-gathering regions, thus, the success of urban sprawl management in such environment is dependent to identifying the relationship between urban sprawl attributes and the responses of their driving factors [36-38].

Since 1950s, Egypt witnessed rapid urbanization that caused unplanned urban sprawl of residential, industrial, and commercial uses around major regions. Land development continued without a proper control and the built-up land has grown rapidly, particularly in the peripheral areas. The GCMR witnessed unprecedented urban sprawl rates during the last 30 years in all of the three study subsectors of this part [44-48]. Unplanned residential uses accommodate between 12–17 million inhabitants, or about 40–50% of Egypt's urban population [43]. Despite 30 years of efforts by the government to manage urban sprawl, unplanned settlements around the Greater Cairo metropolitan Region (GCMR) became a home for more than 7 million people in 1998 [44-46]. In 2006, unplanned residential areas in GCMR became a home for more than 65% of total population of GCMR. The ratio of population growth in these unplanned areas was higher than other Egyptian areas with an increase of 2% from 1996-2006 [44-47].

Observing future urban sprawl offers a picture of where sprawl is occurring, and aids to discover the environmental and natural resources threatened, and proposes the expected future directions and forms of sprawl, moreover helping in understanding the nature of this phenomenon. The power to manage urban sprawl is located in local municipal governments that vary significantly in terms of capability to address informal urbanization issues. An approach is thus required to aid assessing the haphazard urban sprawl phenomenon, trying to estimate future urban sprawl, and evaluating planning acts' influence of the hinder/ increase of urban sprawl at the cost of agricultural areas. This will offer infrastructure for complex urban environment, and updated information related to the sprawl dynamic processes within GCMR in Egypt.

In this paper, we simulated urban sprawl in the context of GCMR as uncoordinated and unauthorized urban development of main core areas in the direction of countryside. We highlighted a strong need to explore the consequence of urban sprawl dynamics on agricultural lands in GCMR to better help for management plans. Consequently, the current study was performed to examine the historical LUC and identify the future trends of urban sprawl and their influences in agricultural lands in GCMR. This study combined prospective analyses of the period from 2004 to 2013 and modelling for 2035 using the new LR-MC-CA model. We were specifically interested to 1) quantify land use transitions from agriculture to urban areas using historical land use data, 2) predict agriculture loss within the next 20 years and 3) determine the best urbanization scenario in Egypt in order to protect cultivated lands.

6.2 Methods and Data

6.2.1 Study area

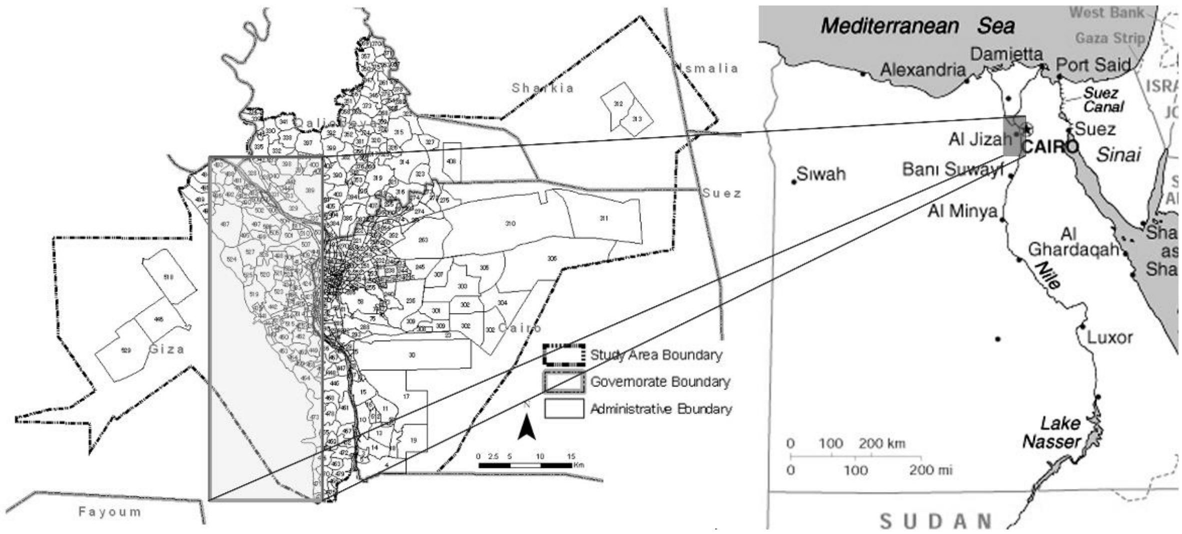


Figure 6.1 Study area

Study area is located at latitude 30° 06′ N and longitude 31 28′ E at an altitude of 74.5 m. The region is located in the east of the River Nile south of the Nile Delta. It is bordered from the west of the urban area of Giza Governorate on the western banks of the River Nile (Figure 6.1). The region is demarcated by El Moqattam hills to the southeast and desert areas in east side borders. The southern border of the Governorate of Qalyubia-which is the northernmost reach of GCMR borders and Cairo governorate from the northwestern side. The GCMR includes part of the Nile Delta arable land and the River Nile from the west and bare desert lands of the east. GCMR has a wide diversity of urban characteristics, such central business district, high-class residential areas, low-class residential areas and unplanned areas. All of these divisions have a high building and population densities. All of the districts in GCMR are mixed with commercial, public, and sometimes industrial uses within the same block. However, (A) variations can be identified easily between high-class residential areas with a lower density of population (6300 people/km2); (B) low and middle-class residential areas with higher density in addition to informal urban areas (44 800 people/km2). The location of our research area is shown in figure 6.1 located in the eastern part of GCMR, part of the Giza governorate with a length of about 18km and width of 15.5km. The area covers about 279 sq. km and implicates a diverse land uses and urban densities.

6.2.2 Datasets

A research by satellite images detected that the surface area covered by urban sprawl in GCMR from 1991-1998 grew by 3.4 % per annum, while the population living in the informal areas grew by 3.2 % per annum. On the other hand, between 1986 and 1996, the population growth rate of informal settlements reached 3.4% per year compared to 0.3% informal areas. And the growth of informal was estimated 3.2% per year, compared to 1.1% in formal areas, and the erosion of arable lands since 1980 was 1 million Acres [46, 47, and 49], which represents around 12% of total agricultural land in Egypt. The value of all arable lands which converted to informal areas was estimated by US$ 46.2 billion, in addition to US$ 63.1 billion as the cost of the 7.9 million informal buildings [50, 51].

In this study, all images were acquired from the U.S. Geological Survey [63, 64]. The driving factors that cause urban sprawl were identified, and LUC based on past alterations and the driving factors were computed. As supplementary data, 1/10,000, and 1/5000 detailed land use for 2004 and 2013 used in this study came from the land use database of general organization of physical planning (GOPP) in GCMR, which were utilized for classifying the images and for preparing the driving factors layers. To prepare the satellite images and to model the urban sprawl, the IDRISI 17.0 Selva software package, ARIS Grid Editor, operating in ArcGIS 10.0 software, were used to enhance the classified images. To build a model of urban sprawl, the IDRISI CA-MC and The Land Change Modeler (LCM) modules were utilized (Figure 6.2).

According [34, 65] to a review of common driving factors used in LUC modelling, two categories of driving factors , (1) environmental, and (2) socio-economic driving factors used to simulate LUC. The utilized geospatial and attribute data in this study are listed in Table 6.1. Kappa index used to calculate the accuracy of classified image. The accuracy of the land use maps generated by GOPP enabled the correction of misclassifications and wrong attributes. The land use maps between 2004 and 2013 was chosen for the model calibration.

Table 6.1 Data sources and types

Data type	Dataset	Source	Resolution (m)
Landsat images	TM for 1984, and ETM for 2004, and 2013	U.S. Geological Survey	30
Environmental Features	Land use maps, urban areas, administrative boundaries, roads network, River	GOPP	30

6.2.3 Integrating LR-MC-CA model

In urban areas, LU system is exposed to strong pressure by humans. So, urban areas have complex spatio-temporal alteration dynamics [66] which affect natural resources, the environment, socio-economic driving factors. Finding the alterations and their reasons would aid identify potential future alterations, decision-support stages, and the structure of various LUC scenarios [67]. LUC analysis is built based on the historical alterations from time t1 to t2 [68]. Based on the investigation of LUC, the alteration from one class to another within a specific period is identified, thus revealing the relations among the classes [66]. In this paper, cross-tabulation analysis [68] was used to identify the LUC over 1984–2004 and 2004–2013. The areas that changed from one class to another at specific periods can be observed quantitatively and spatially [69]. The cross-tabulation table identifies the frequencies of altered or no altered classes [53].

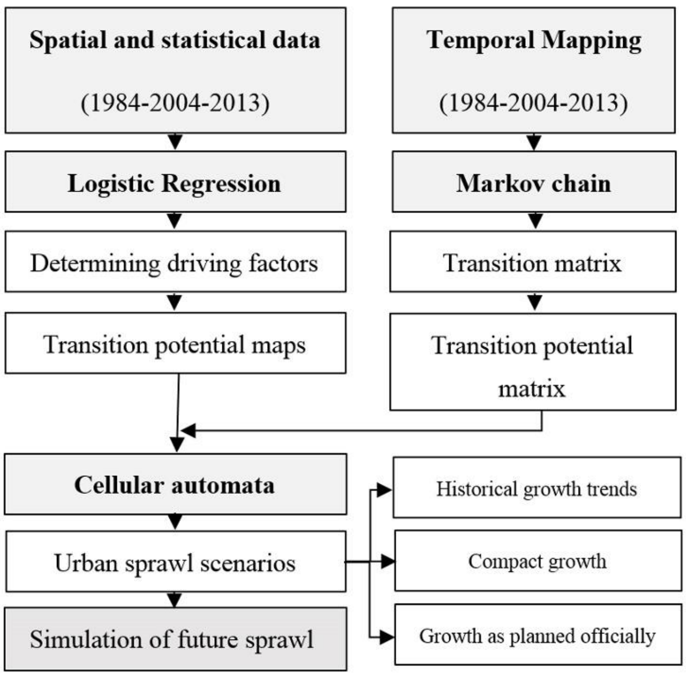


Figure 6.2 Study method chart.

The urban sprawl modelling by coupling the LR, MC and CA (LR-MC-CA) methods is built to enhance the quality of the standard LR model, the detailed phases are shown in Figure 6.2. First, LU maps in 2004 and 2013 were obtained with Idrisi selva 17.0 application, the main driving factors determining LUC by LR model were examined and the transition potential maps of urban sprawl were acquired. The transition probability matrices of LUC were utilized in the next step to recognize the future structure of LUC based on the MC model. A customized CA model was built to spatially assign the projected LUC along with geospatial models to recognize the future urban sprawl patterns. To prove the results, LU map of 2013 was estimated and compared against real LU maps. Finally, by setting three different scenarios, the model was utilized to identify future patterns of urban sprawl for 2035.

A. Logistic regression model

LR is a method to determine the relationships between a binary-dependent variable and several independent categorical and continuous factors, can fit spatial processes, and LUC outcome reasonably well. Though, there are several constrains in modelling LU distribution using LR models such as ignoring the autocorrelation among socio-economic factors, which affect negatively on the goodness of LU modelling accuracy, and It is important to account for spatial autocorrelation in LUC modelling. An LR model was developed by combining the LR model with auto-correlation effects, which adds an auto covariate term to describe the influence of the neighborhood analysis. This extra explanatory factors captures the variability of the response variable y in the spatial neighborhood. In this paper, geo-statistical methods identify the specific neighborhood size for each LU, and a set of best fit models with maximum $r2$ values was created [70]. Precisely, we use the LR models to examine the driving factors and transition probability maps of urban sprawl in GCMR.

B. Markov chain model

MC is a special random moving from one state to another at each time phase which probability distribution over the next state is projected to only depend on the current state, but not on the previous ones [71]. MC analysis is an appropriate tool for modelling LUC when alterations in the landscape are hard to explain. The model can be served as a metric of the direction of alterations in the future due to the capability to describe projection trends of LUC [72]. In this paper, MC analysis is utilized to compute the transition area matrix of LUC, and to identify the quantity of LUC. The transition area matrix for simulation periods is created by the MC module in IDRISI selva 17.0.

C. Cellular automata

A CA consists of a discrete cell space with states describe every cell. CA states can be binary values, qualitative values (represent different land uses), quantitative values (represent values like population density, degree of development, or value of buildings) [73-75], and a vector of several attributes [76]. The state of each cell be contingent with its previous state and its neighboring cells based on a set of transition rules [77]. The CA background conventions can limit their ability to model complex geographical phenomena [78], thus, adapting CA to urban simulation needs considering the particularities of this phenomenon that entails a relaxation of the original structure of CA [78].

6.3 Results and Discussions

6.3.1 Monitoring and visualization of urban sprawl

A. Calibrating and interpretation accuracy

For temporal LU mapping, a set of TM/ETM images for the year 2004 and 2013 was chosen to derive LU maps. The mapping required fixed time steps between images, thus images of 2004 and 2013, constituting fixed five-year cycles were selected to be synchronized with the data. The LU map classified from 2004 and 2013 satellite images with the field data collected in 2013 was compared, which showed overall classification accuracy 88.4%, by Kappa coefficients.

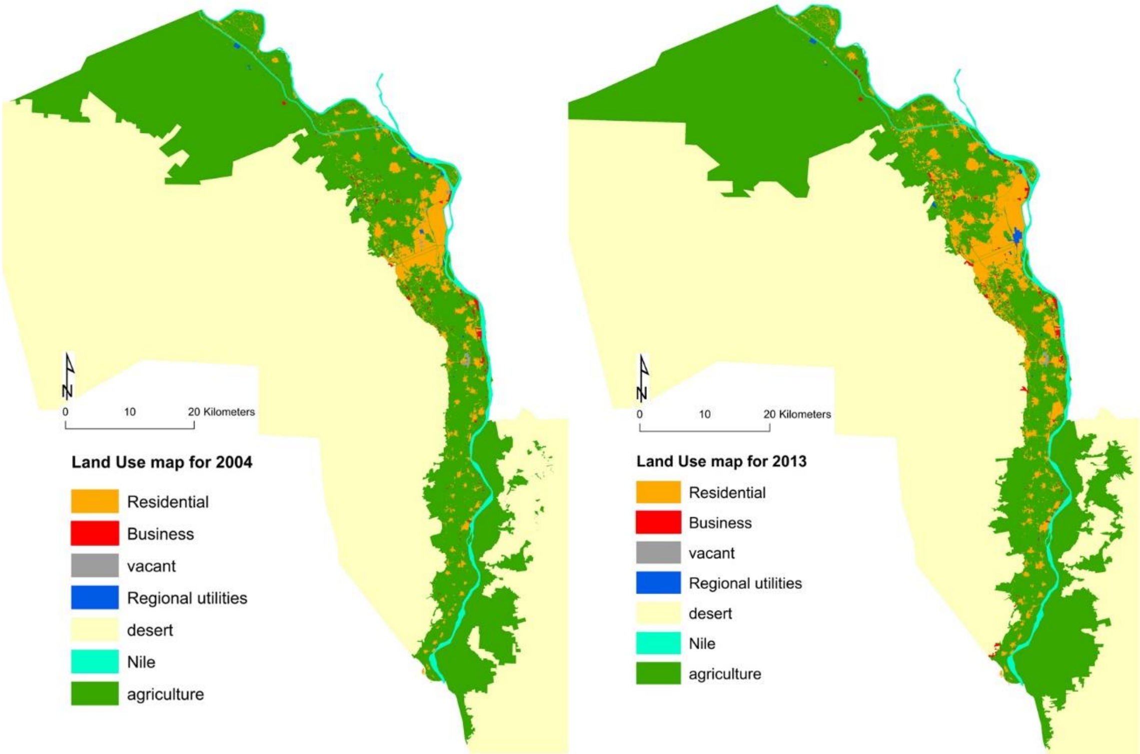


Figure 6.3 Land use maps of 2004, and 2013.

B. Monitoring of land use changes

LUC from 2004 to 2013 were measured to quantify the quantity and location of alterations. According to Table 6.2, most LUC replaces the Agricultural lands with the urban uses. Overall, 74.1 sq. km ha have been altered to urban uses in the study period. The analysis displays a wave of LUC in the north, south peripheries counties of the study area due to the instability of security condition since 2011 which let people to build out of law in prohibited agriculture land zones [44, 46, and 48]. For the period of 2004-2013, noticeably the most dramatic urban sprawl has occurred around the roads and urban counties in the northern countryside counties [44, 46]. Figure 6.4 shows the urban sprawl during 2004-2013. It can be seen that a rapid growth of built-up areas occurred surround whole GCMR counties with no difference between major or minor counties. Additionally, a scatter built-up patches occurred for the first time in agricultural lands in sites nearby major roads, and they were scattered in the peripheral counties around the major areas.

Table 6.2 Land use change over time in sq. km of each category

Category	1984	2004	2013	1984-2004	2004-2013
Residential lands	88.5	137.4	205.9	48.9	68.5
Business	4.0	10.6	14.0	6.6	3.4
vacant	0.5	2.7	1.3	2.2	-1.4
Regional Utilities	0.8	2.5	4.7	1.7	2.2
Nile	72.9	72.8	72.8	-0.1	0
Old Agricultural lands	733.5	618.9	546.2	-114.6	-72.7
New reclaimed desert lands	0	839.4	1066.8	839.4	227.4
Total Agricultural lands	733.5	1458.3	1613.0	724.8	154.7

6.3.2. Identifying driving factors and transition potential maps of urban sprawl

A. Identifying driving factors

In the preparation of LUC suitability layer, the driving factors responsible for urban sprawl in GCMR were identified. Urban sprawl is generally the outcome of complex interactions between many driving factors. Therefore, a driver set that is universally defined in all studies for all areas is difficult to generate [69, 79]. Though, based on literature review, similar driving factors were utilized in similar studies and it was decided to use the driving factors in this study in Table 6.3 [66, 69, and 79]. Moreover, unsuitable areas for urbanization were recognized as constraints. The existing urban areas, water-covered areas and military locations were evaluated as the areas not suitable for urban sprawl. The constraint areas were masked to exclude them from the LUC simulation.

Moreover. It was supposed that some physical driving factors, such as Distance to major roads, Nile River, urban centers, and urban cells within Neighborhood, would correspond to the urban sprawl in the GCMR. Thus, the aim is to discover the positive or negative influences of each particular factor (Table 6.3). The LR produces odds ratios related to each predictor value. The LR was estimated for 9 different sets of variable combinations to find the highest possible relative operating characteristic (ROC) and adjusted odds ratio values. The odds ratio displays the degree of correlation or non-dependence between two binary data that is known as the measure of effect size, which is important index of LR and is utilized as a descriptive statistic.

Although, other methods of measuring the relationships for paired binary data, such as the relative risk, the odds ratio compares the two respective factors symmetrically, it and can be computed by some types of non-random samples, and show the likelihood of an occurrence relative to the likelihood of a nonoccurrence. We used ROC method to assess the performance of the approach due to it assesses how well a pair of maps fits in terms of the location of developed pixels [80]. Fundamentally, ROC = 1 indicates a perfect fit, ROC = 0.5 indicates a random fit, a higher adjusted odds ratio is estimated for a better fit and higher validity [31]. In his study, the value of ROC is 0.94, which verifies the accuracy of this model performance (Table 6.3).

Driving factors with positive values have a positive influence on LUC and thus support urban sprawl (e.g., proximity to the Nile River, proximity Regional utilities, and proximity to roads). While other drivers return to negative values, the attraction for urban sprawl falls significantly (e.g., proximity to existing urban centers, proximity to wells, proximity to counties, and proximity to business location) Table 6.3. The LR model result shows the probability surface of occurrences for all driving factors, which vary in the range between 0 and 1, and states the probability of an event as a proportion of both incidence and non-incidence.

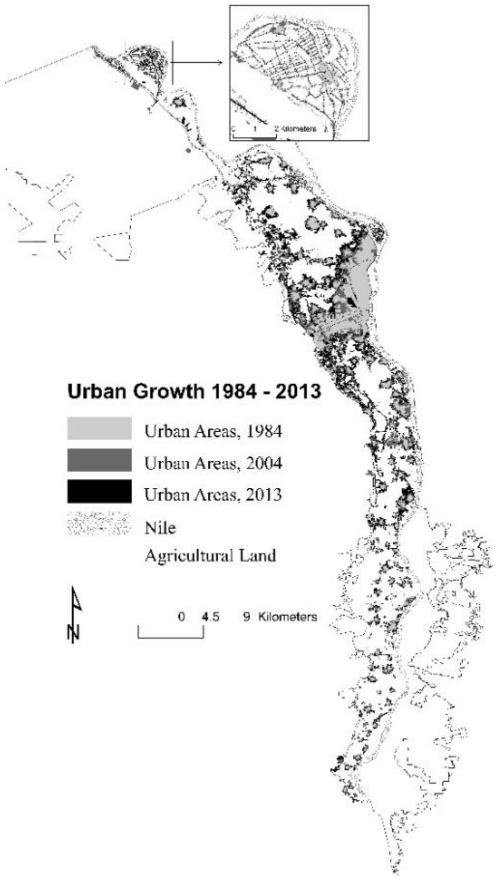


Figure 6.4 Spatial patterns of urban sprawl during 1984, 2004, and2013.

B. Visualization of transition potential maps

By LR, the probability surfaces for causing driving factors was computed then, they applied in Idrisi selva 17.0 and combined by the Map Calculator function. The output map showed that the growth of urban uses in GCMR had a multi-directional sprawl forms (Figure 6.4). The computed probability model by LR model showed that the certain case of mis-simulation pixels still exist. However, visual representation of probability of urban uses showed high quality probability map, but it has not the capability to specify the amount and location of LUC without integration with other methods. Therefore, probability map will be combined with MC model to identify LUC, and CA to spatially allocate the computed variations.

Table 6.3 Logistic regression model for land uses change 2004-2013.

Variable	Built-up land
Distance to Major roads	-0.64
Distance to urban centers	-0.28
Distance to wells	-0.25
Distance to Business locations	-0.16
Distance to Residential uses	-1.40
Number of urban cells within a 7 by 7 Moore Neighborhood	0.34
Distance to Nile River	0.19
Constant	5.11
ROC	0.94

C. Testing the Selected Driving factors

In the MC simulation, to quantify the relationship between each LU with causing driving factors, a Cramer's V analysis was performed, which is a way of computing correlation in tables with more than 2 × 2 rows and columns [82]. Cramer's V value ranges from 0 to 1.0 that makes it proper to compare the strength of relationship between any two cross classification tables [83, 84]. Cramer's V values higher than 0.15 can be measured as proper value to evaluate the driving variables [68].

Table 6.4 Markov transition probabilities for the periods 2004-2013

	Residential	Business	Vacant	Utilities	Desert	Nile	Agriculture
Residential	0.9450	0.0078	0.0000	0.0472	0.0000	0.0000	0.0000
Business	0.0000	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
Vacant	0.6411	0.2942	0.0417	0.0230	0.0000	0.0000	0.0000
Utilities	0.7694	0.0084	0.0000	0.2222	0.0000	0.0000	0.0000
Desert	0.0149	0.0017	0.0000	0.0003	0.7972	0.0000	0.1859
Nile	0.0000	0.0015	0.0000	0.0000	0.0000	0.9985	0.0000
Agriculture	0.1762	0.0034	0.0000	0.0048	0.0000	0.0000	0.8156

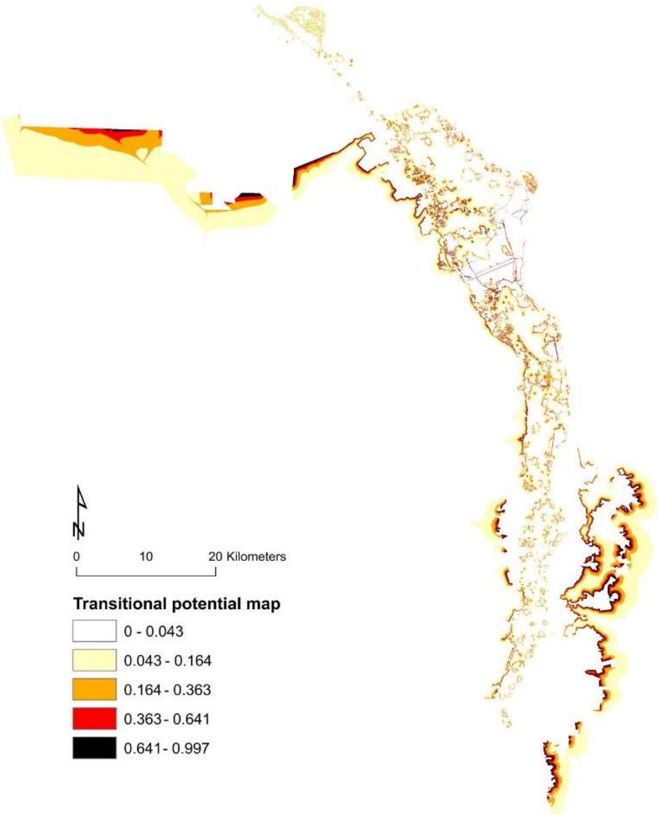


Figure 6.5 Transitional potential map for land use change 2004- 2013.

6.3.3. Computing transition matrix of urban sprawl

A. Computing past transition matrix

According to LUC 2004-2013, the transition matrices were computed using MC method (Table 6.4). The diagonal elements indicate to probability values for self-replacement and LU types that remain without change while, off-diagonal values refers the probability of alterations from one LU type to another. The agricultural lands had a higher probability of altering into urban uses particularly residential uses, which was greater in 2004-2013 comparing to 1984-2004. Moreover, the tendency of LUC to other categories (Business uses, vacant lands, and regional utilities) in 1984-2004 were likely to be changed into residential in 2004-2013, and the total agricultural land loss was 5.08 % in this last nine years, regardless the new desert reclamation lands occurred during this period.

B. Computing transition matrix

The transition area matrix is a table that include the amount of pixels that are expected to convert from one LU category to other. The results of the transition area matrix for 2004-2013 are applied for computing LU classes and estimate the quantity of alterations which expected to be inputs for CA. MC is not a spatially explicit model, thus it is not a suitable model to determine the location of LUC that requires an integration with other spatial models. Therefore, CA is selected to spatialize the expected LUC quantity. However, it is an appropriate quantity estimator for the results to be allocated, thus we used it to calculate the amount of LUC for 2013 (Table 6.5). For model validation, the probability map for 2013 was applied to allocate the quantity of LUC by the customized CA function to create a 2013 LU modelled map to compare with the 2013 actual map. Kappa statistic was used and revealed an index of 0.884 which verifies the simulation process and approve model accuracy to complete simulation for 2035 [81].

Table 6.5 Modelled transition area matrix in sq. km by MC for 2004 - 2013.

	Residential	**Business**	**Vacant**	**utilities**	**desert**	**Nile**	**Agriculture**
Residential	194.45	1.60	0	9.7	0	0	0
Business	0	13.97	0	0	0	0	0
Vacant	0.81	0.37	0.05	0.02	0	0	0
utilities	3.62	0.03	0	1.04	0	0	0
desert	59.82	6.73	0	1.10	3,197.33	0	745.78
Nile	0	0.10	0	0	0	72.69	0
Agriculture	284.35	5.43	0	7.76	0	0	1,315.88

6.3.4 Scenario simulation of forms of urban sprawl

A. Scenario setting

In addition to the historical trends scenario, we examine two other sets of scenarios. The bases for scenario design are as follows. First, it is noteworthy that in the early stage of urbanization in the study area, the urban development has been meeting in informal way the needs of economic and social rapid evolution so that the areas of agricultural lands decreased rapidly [44, 46, and 48], which means an environmental and food production services loss. Therefore, it is called for keeping the areas of the agricultural lands to satisfy theses needs and achieve an environment balance. Second, according to GCMR urban development Plan [85], the future urban sprawl will be restricted around central counties. In response to the needs, three sets of policy scenarios on urban sprawl were designed: (1) the historical growth trend (HGT) scenario, which was aimed to identify the future forms of urban sprawl without any limitation and keeps a continuation of the historical trend; (2) the Compact growth (CG) scenario, which reflected a stronger commitment to protecting environment and conserving aquatic ecosystems. Thus, the excluded layer which includes the agricultural lands, and the water bodies buffer is not allowed to be urbanized ; and (3) growth as planned officially (GPO) scenario, which was designed to comply with the urban sprawl restriction policy addressed in official GCMR development Plan. Thus, the three scenarios, HGT, CG and GPO, were defined and transplanted into the CA model.

B. the Historical growth trend (HGT) scenario

Based on the transition potential map and LUC trend, CA first inputs the transition probabilities for 2004-2013 to project the previously LU for 2013. The CA allocated the cells by means of a 7 by 7 neighborhood matrix and one iteration per year. By assuring the model qualification and validation process, urban sprawl was computed for 2004 and 2013. Modelled LUC map were identified for 2013, based on the LU data 2004 -2013, and compared with the actual 2013 LUC map to calculate the kappa index calculated 88.4% which confirmed a high matching between the modelled LUC and the actual one that proves the chosen model parameters were suitable for modelling.

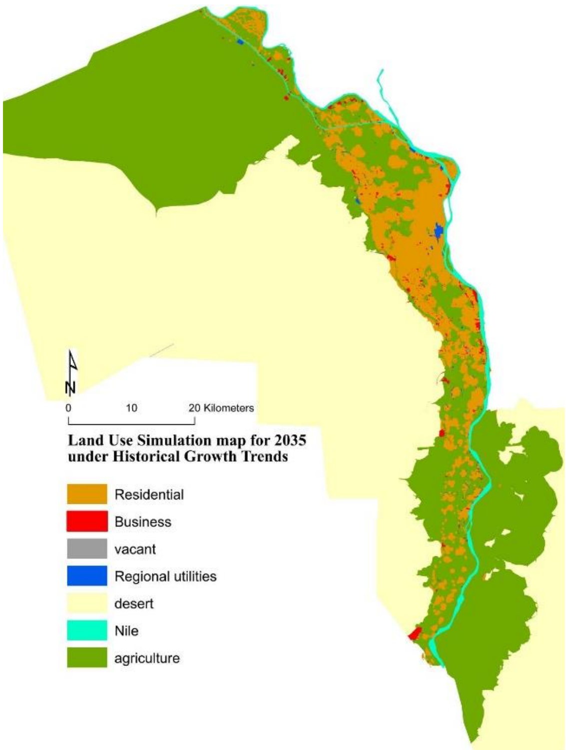


Figure 6.6 Land uses in 2035 under the HGT scenario.

Therefore, the simulation model was refitted with similar variables settings using LU data from 2013, transition probabilities from 2004 to 2013, and the identical potential map. The future urban sprawl was then identified for the years 2013. Finally, the spatial arrangement of LUC modeling for 2013 was examined by means of point type analyses. Quadrat count tests, and spatial Kolmogorove-Smirnov tests were applied, which assess the significance of spatial forms by comparing the null hypothesis of complete spatial randomness of modelled LUC. With p ≤ 0:001, the quadrat count and Kolmogorove test confirmed a spatially random distribution, which suggests an important clustered forms of future urban sprawl. Under the HGT scenario (Figure 6.6), the urban sprawl will continue emerges in whole study urban areas both minor and major counties. Moreover, the built-up areas will continue sprawl along with the road networks. Under this scenario, the total simulated urban area for 2035 was about 411.3 Sq. Km. The net rise in urban land from 2013 to 2035 was about 186.7 Sq. Km, identifying a raise of 83.12 % in comparison with the basic area in 2013. By 2035, the agricultural land will lose 11.57 % of existing 2013 area regardless the potentials of new desert reclamation until 2035.

Table 6.6 Land-use in 2035 predicted from the three potential development scenarios in sq. km

	2013 land-use	HGT scenario	CG scenario	GPO scenario
Residential	205.9	383.3	219.3	220.1
Business	14.0	20.6	17.9	20.3
vacant	1.3	0.2	1.0	0.6
Regional	4.7	7.4	5.1	7.4
desert	4011.0	3546.9	3546.9	3546.9
Nile	72.8	72.8	72.8	72.8
Agriculture	1613.0	1889.8	2058.0	2052.9

C. The Compact growth (CG) scenario

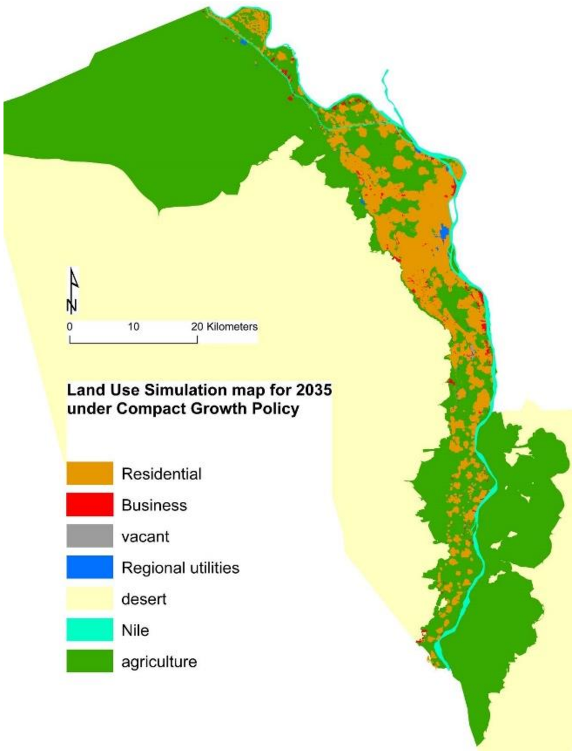


Figure 6.7 Land uses in 2035 under the CG scenario.

To protect the agricultural lands in the study area in the CA model, first, any residential construction, business uses or new roads will not be allowed to be developed within the agriculture areas in the GCMR. New limited development areas will not be allowed for establishing new urban centers. Second, the excluded layer including the Agriculture lands, canals buffer strips and the roads buffers will not be allowed for being occupied. Particularly, the minor roads and minor urban areas are not at all allowed to be urbanized. As shown in figure 6.7, the modeling result shows that the speed of urban sprawl will decrease and the built-up areas will grow more compactly rather than the HGT scenario; the urban sprawl will only discontinuously expand around specific main urban areas such as Giza to fill available vacant lands spots. This CG scenario assumed slowing down of the urban sprawl rates and changing the forms of growth while preserving the livability of the region. Based on this scenario, the simulated urban land for 2035 was about 242.3 Sq. Km. The net rise in urban land from 2013 to 2035 was 17.1 Sq. Km, identifying a raise of 7.88 % in comparison with the basic area in 2013. By 2035, the agricultural land will lose 1.06% of existing 2013 total area regardless the potentials of new desert reclamation lands.

D. The Growth as planned officially (GPO) scenario

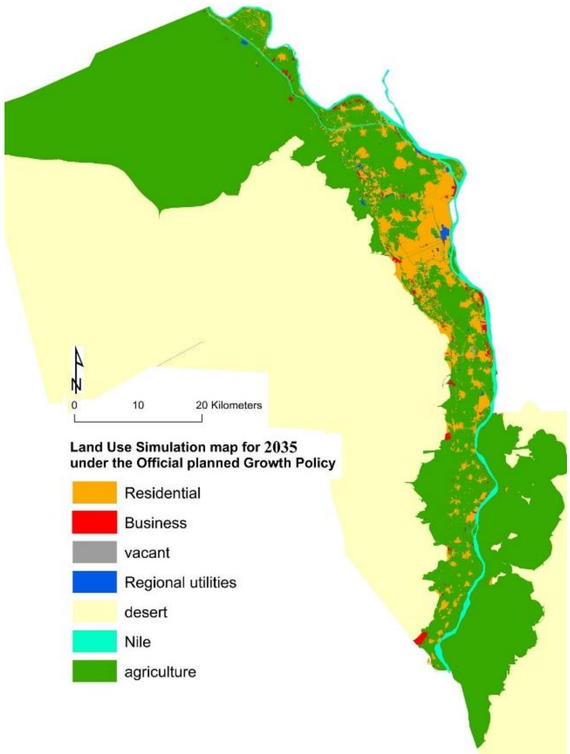


Figure 6.8 Forms of urban sprawl under the GPO scenario.

According to the GCMR Plan [85], urban sprawl is only allowed in previous planned urbanizing areas, and agriculture areas will be restricted to maintain constant, which reflects a stringent set of policies targeted toward sustainable urban growth and Agricultural lands protection. The data elements for the excluded layer are similar to those under the CG scenario, but urban development is stringently controlled through urban planning. In the CA model, the breed and spread are the important parameters which can control the trend of urban sprawl and its effects, so we add two parameters of the breed rate and spread rate to build the GPO scenario. The final modeling map was evaluated to provide clues as to the cut-off point for attaining the goal of economic development. As Figure 6.8, there will be a more patches of urban sprawl forms in GCMR. The urban sprawl will go on by connecting the road networks and highways. Under this scenario, the total simulated urban area for 2035 was about 247.8 Sq. Km. The net rise in urban land from 2013 to 2035 was about 23.2 Sq. Km, identifying a raise of 10.32 % in comparison with the basic area in 2013. By 2035, the agricultural land will be reduced by 1.43% comparing to 2013 area regardless the potentials of desert reclamation until 2035.

6.4 Conclusion

The most significant finding of this study is dispel the highly concerns about the disappearance of farmland in GCMR in the future due to high urbanization rates since 1960s. In developing countries, urban sprawl is related to particular problems that result in uncontrolled alterations, thus determining the existing spatial use and urban sprawl dynamics is the most significant analysis issue in contemporary urban research. GCMR has experienced fast urbanization in latest years, As a consequence of this fast urbanization, GCMR is faced with the issue of the obliteration of natural resources. This paper focused on the precise determination of the future urban sprawl potential and related natural areas that are at risk due to sprawl. Consequently, the simulation and forecast of urban sprawl is a necessary task for urban planners to frame sustainable development policies. In this analysis, an LR model was combined with the MC and CA models to an effective geospatial explicit approach. The LR model can explore relationships between LUC and causative driving factors quantitatively, which enables us to differentiate the significant driving factors. Nevertheless, the simple LR model has severe limitations due to the being of spatial autocorrelations of socio-economic drivers in LUC. So, the current approach was built to correct the above-mentioned limitations, and to determine the interaction of numerous environmental and socio-economic drivers which may effect on urban sprawl process. In this study, combined simulation model was used to recognize the dynamics, forms, and trends of urban sprawl that may be faced through 2035. Thus, the urban dynamics was observed by using Landsat TM/ETM satellite images from 1984, 2004 and 2013 and urban sprawl simulations were recognized using MC models. The accuracies of the simulation models were measured for 2013, and the 2035 scenario was computed with the LR-MC-CA model, which provided superior results. This simulation provides insight into the quantity and location of possible alterations, and spatially and quantitatively identified the potential risks of urban sprawl in GCMR until 2035.

Numerous driving factors were taken into account, which were supposed to lead to urban sprawl in GCMR. But, less causative driving factors were excluded by the LR modelling to enhance the quality of the model after consideration of possible set of the driving factors. The LR shows that some drivers have a positive influence and consequently they support urban sprawl, while other drivers have negative values so that the attraction for urban sprawl falls considerably. The ideal set of driving factors was chosen according to the computed ROC values as an input into the established method to compute the forms of urban sprawl in GCMR for 2013. The MC model is working to identify the probability of change of one state to another. The model creates two tables: a transition probability matrix, which computes the probability of alterations from one to another category, and transition area matrix, which finds the number of cells of one land type to be changed to another type. The MC confirms the simulation process and the approach can also be performed for future years. But, for that MC is not a spatially explicit model, it is not a proper model to identify the location of alterations, which requires to be combined with spatial models. Thus a combination of LR-MC-CA was built to spatialize the projected change quantity. By setting three scenarios, in line with the planning demand, the result displays that the urban sprawl will significantly vary under these scenario simulations. Under the HGT, and GPO scenarios, the urban sprawl will emerge the whole study urban areas, while under CG scenario, the urban sprawl will discontinuously expand around with Major urban areas only, or continue surround the Major road networks. By comparing these scenarios influences, the results show that just under the HGT scenario, the sustainable development in GCMR cannot be assured in the future, while under the CG scenarios, the Agriculture lands erosion-risk level will be much lower than that under the HGT and GPO, proving that the CG scenario was more effective in meeting the goal of environment protection and urban sustainable development of JICA, 2008 for the study area [85].

Our analysis proves that urban modelling offers a superior explanation of the futures and trends that urban sprawl will face. It also shows significant information for policies directed at sustainable regions. However, the method can combine various driving factors, it has certain constrains in parallel models, like the non-factoring of behaviors, individuals, governmental actions and personal preferences in LU conversions. Thus, future studies should be fulfilled by agent-based modelling on the same study area to compare their consequences on LU dynamics and intensity analysis with existing utilized models. Furthermore, to explain whether the simulated forms of urban sprawl are precise to GCMR, this method requires further comparative studies. Finally, these notable relevant results should guide urban planners, policy makers and land management authorities to make a realistic policy for the sustainable development in GCMR. This will aid them in adjusting urban sprawl and notify them of the extent of expansion that can be projected. Thus, they can put forward proper policy interventions to manage the inevitable urbanization processes. Planning and urban management in Egypt require new skills and approaches to enhance the quality of infrastructure, energy efficient service provisions, and environmental conditions to sustain growth and attract foreign investment. The GCMR urban authorities should implement new tools such as RS and GIS to be capable of providing the necessary information for urban plans and as monitoring tools during the execution of plans.

References

[1] Glaeser, E.L., and M.E. Kahn. 2004. "Sprawl and Urban Growth." In Handbook of Regional and Urban Economics, Edition 1, Volume 4, Chapter 56, edited by J.V. Henderson and J.F. Thisse, 2481_2527. Amsterdam: Elsevier.

[2] Helbich, M., and M. Leitner. 2010. "Postsuburban Spatial Evolution of Vienna's Urban Fringe: Evidence from Point Process Modeling." Urban Geography 31 (8): 1100_1117.

[3] Gillham, O. 2002. The Limitless City: A Primer on the Urban Sprawl Debate. Washington, DC: Island Press.

[4] Koomen, E., J. Stillwell, A. Bakema, and H.J. Scholten, 2007. Modelling Land-Use Change: Progress and Applications. Dordrecht: Springer.

[5] Bagan, H., and Y. Yamagata, 2012. "Landsat Analysis of Urban Growth: How Tokyo Became the World's Largest Megacity During the Last 40 Years." Remote Sensing of Environment 127: 210_222.

[6] Bhatta, B., S. Saraswati, and D. Bandyopadhyay, 2010. "Urban Sprawl Measurement from Remote Sensing Data." Applied Geography 30: 731_740.

[7] Patino, J.E., and J.C. Duque. 2013. "A Review of Regional Science Applications of Satellite Remote Sensing in Urban Settings." Computers, Environment and Urban Systems 37: 1_17.

[8] Overmars, K.P., and P.H. Verburg. 2006. "Multilevel Modeling of Land Use from Field to Village Level in the Philippines." Agricultural Systems 80: 435_456.

[9] Mahiny, A.S., and K.C. Clarke. 2012. "Guiding SLEUTH Land-Use/Land-Cover Change Modeling Using Multicriteria Evaluation: Towards Dynamic Sustainable Land-Use Planning." Environment and Planning B: Planning and Design 39: 925_944.

[10] He, J., Y. Liu, Y. Yu, W. Tang, W. Xiang, and D. Liu. 2013. "A Counterfactual Scenario Simulation Approach for Assessing the Impact of Farmland Preservation Policies on Urban Sprawl and Food Security in a Major Grain-Producing Area of China." Applied Geography 37: 127_138.

[11] Shafizadeh Moghadam, H., and M. Helbich. 2013. "Spatiotemporal Urbanization Processes in the Megacity of Mumbai, India: A Markov Chains-Cellular Automata Urban Growth Model." Applied Geography 40: 140_149.

[12] Jokar Arsanjani, J., M. Helbich, W. Kainz, and A. Darvishi. 2013. "Integration of Logistic Regression, Markov Chain and Cellular Automata Models to Simulate Urban Expansion: The Case of Tehran." International Journal of Applied Earth Observation and Geoinformation 21: 265_275.

[13] Batty, M., and P. Longley, 1994. Fractal Cities: A Geometry of Form and Function. 1st ed. SanDiego, CA: Academic Press.

[14] Longley, P.A. 2002. "Geographical Information Systems: Will Developments in Urban Remote Sensing and GIS Lead to 'Better' Urban Geography?" Progress in Human Geography 26 (2): 231_239.

[15] Jiang, B., and X. Yao, eds. 2010. Geospatial Analysis and Modelling of Urban Structure and Dynamics. Dordrecht: Springer. ISBN 9048185718.

[16] Wang, J., X. Liu, L. Peng, H. Chen, L. Driskell, and X. Zheng. 2012. "Cities Evolution Tree and Applications to Predicting Urban Growth." Population and Environment 33 (2): 186_201.

[17] Perez, L., and S. Dragicevic. 2012. "Landscape-Level Simulation of Forest Insect Disturbance: Coupling Swarm Intelligent Agents with GIS-Based Cellular Automata Model." Ecological Modelling 231: 53_64.

[18] Robinson, D.T., D. Murray-Rust, V. Rieser, V. Milicic, and M. Rounsevell. 2012. "Modelling the Impacts of Land System Dynamics on Human Well-Being: Using an Agent-Based Approach to Cope with Data Limitations in Koper, Slovenia." Computers, Environment and Urban Systems 36 (2): 164_176.

[19] Koomen, E., D. Vasco, J.E.C. Dekkers, and P. Rietveld. 2012. "A Utility-Based, Multisector Framework for Local Scale Land-Use Modeling." Paper presented at the workshop on complexity modeling for urban structure and dynamics for the 15th AGILE International Conference on Geographic Information Science, Avignon, April 24_27.

[20] Torrens, P.M. 2006. Geo simulation and its Application to Urban Growth Modeling. London: Springer-Verlag.
[21] Han, J., Y. Hayashi, X. Cao, and H. Imura. 2009. "Application of an Integrated System Dynamics and Cellular Automata Model for Urban Growth Assessment: A Case Study of Shanghai, China." Landscape and Urban Planning 91: 133_141.
[22] Wang, H., S. He, X. Liu, L. Dai, P. Pan, S. Hong, and W. Zhang. 2013. "Simulating Urban Expansion Using a Cloud-based Cellular Automata Model: A Case Study of Jiangxia, Wuhan, China." Landscape and Urban Planning 110: 99_112.
[23] Kamusoko, C., M. Aniya, B. Adi, and M. Manjoro. 2009. "Rural Sustainability Under Threat in Zimbabwe _ Simulation of Future Land Use/Cover Changes in the Bindura District Based on the Markov-Cellular Automata Model." Applied Geography 29: 435_447.
[24] Clancy, D., J.E. Tanner, and S. McWilliam. 2010. "Quantifying Parameter Uncertainty in a Coral Reef Model Using Metropolis-Coupled Markov Chain Monte Carlo." Ecological Modelling 221: 1337_1347.
[25] Benito, P.R., J.A. Cuevas, R.B. delaParra, F. Prieto, J.M.G. delBarrio, and M.A. Zavala, 2010. "Land Use Change in a Mediterranean Metropolitan Region and its Periphery: Assessment of Conservation Policies through CORINE Land Cover Data and Markov Models." ForestSystems 19: 315_328.
[26] Shi, Y., X. Sun, X. Zhu, Y. Li, and L. Mei. 2012. "Characterizing Growth Types and Analyzing Growth Density Distribution in Response to Urban Growth Patterns in Peri-urban Areas of Lianyungang City." Landscape and Urban Planning 105 (4): 425_433.
[27] Tayyebi, A., B.C. Pijanowski, and B. Pekin. 2011. "Two Rule-Based Urban Growth Boundary Models Applied to the Tehran Metropolitan Area, Iran." Applied Geography 31 (3): 908_918.
[28] Huang, B., L. Zhang, and B. Wu. 2009. "Spatiotemporal Analysis of Rural_Urban Land Conversion." International Journal of Geographical Information Science 23 (3): 379_398.
[29] Vaz, E., P. Nijkamp, M. Painho, and M. Caetano. 2012. "A Multi-scenario Forecast of Urban Change: A Study on Urban Growth in the Algarve." Landscape and Urban Planning 104: 201_211.
[30] Verhagen, P. 2007. Case Studies in Archaeological Predictive Modeling. Amsterdam: Amsterdam University Press.
[31] Hu, Z., and C. Lo. 2007. "Modeling Urban Growth in Atlanta Using Logistic Regression." Computers, Environment and Urban Systems 31, 667_688.
[32] Jokar Arsanjani, J., W. Kainz, and A. Mousivand. 2011. "Tracking Dynamic Land-Use Change Using Spatially Explicit Markov Chain Based on Cellular Automata: The Case of Tehran." International Journal of Image and Data Fusion 2: 329_345.
[33] Han, J., Y. Hayashi, X. Cao, and H. Imura. 2009. "Application of an Integrated System Dynamics and Cellular Automata Model for Urban Growth Assessment: A Case Study of Shanghai, China." Landscape and Urban Planning 91: 133_141.
[34] Poelmans, L., and A. Van Rompaey. 2009. "Complexity and Performance of Urban Expansion Models." Computers, Environment and Urban Systems 34 (1): 17_27.
[35] Xie, W., P. Wang, and H.S. Huang. 2013. "Ecological Risk Assessment of Land Use Change in the Poyang Lake Eco-economic Zone, China." International Journal of Environmental Research and Public Health 10: 328_346.
[36] Allan, J.D. 2004. "Landscapes and Riverscapes: The Influence of Land Use on Stream Ecosystems." Annual Review of Ecology, Evolution, and Systematics 35: 257_284.
[37] Alberti, M., D. Booth, K. Hill, B. Coburn, C. Avolio, S. Coe, and D. Spirandelli, 2007. "The Impact of Urban Patterns on Aquatic Ecosystems: An Empirical Analysis in Puget Lowland Subbasins." Landscape Urban Planning 80: 345_361.
[38] Amiri, B.J., and K. Nakane, 2009. "Modeling the Linkage between RiverWater Quality and Landscape Metrics in the Chugoku District of Japan." Water Resources Management 23: 931_956.
[39] Antrop, M., 2000, Background concepts for integrated landscape analysis. Agriculture, Ecosystems and Environment, 77, 17–28.
[40] Mesev, V., 2003, Remotely sensed cities: An introduction. In Remotely Sensed Cities, V. Mesev (ed.), New York: Taylor & Francis.
[41] Weng, Y., 2007, Spatiotemporal changes of landscape pattern in response to urbanization. Landscape and Urban Planning, 81, 341–353.

[42] Miller, R. B. and Small, C., 2003, Cities from space: Potential applications of remote sensing in urban environmental research and policy. Environmental Science & Policy, 6, 129-137.

[43] Kipper, R. And Fischer, M., (eds.), 2009: Cairo's Informal Areas: Between Urban Challenges and Hidden Potentials: Facts. Voices. Visions. Chapter 2: Daily Life in Informal Areas, 49-83.

[44] Taher Osman, Prasanna Divigalpitiya Takafumi Arima, 2016. Measuring Urban Sprawl Patterns in Greater Cairo Metropolitan Region. Journal of the Indian Society of Remote Sensing. Available at: http://link.springer.com/10.1007/s12524-015-0489-6.

[45] Sims, D., & Séjourné, M. (2008). The dynamics of peri-urban areas around greater Cairo: A preliminary reconnaissance. Washington, D.C.: World Bank.

[46] Taher Osman, Prasanna Divigalpitiya Takafumi Arima. (2015). Modeling Urban Growth Scenarios in Cairo Metropolitan Region 2035 , Proceedings of 14th International Conference on Computers in Urban Planning and Urban Management (CUPUM 2015), MIT ,Massachusetts, USA . Available at: http://web.mit.edu/cron/project/CUPUM2015/proceedings/Content/modeling/213_osman_h.pdf

[47] MOP and GTZ, 2004. (Ministry of Planning - German Technical and Financial Cooperation), New Practice of Participatory Local –Development in Egypt's Urban Areas, Policy Paper, Egypt.

[48] Taher Osman, Prasanna Divigalpitiya, Takafumi Arima. Effect of Governmental Housing Regulations on the Egyptian Housing Market: Focusing on Greater Cairo Metropolitan Region, Journal of Architecture and urban Design, Kyushu University, No. 28, pp. 1- 9, July 2015.

[49] Sims, D. (2003). The case of Cairo, Egypt, UN habitat, global report on human settlements 2003, the challenge of slums, Earth scan, London.

[50] El-Hefnawi, A. (2005). Protecting agricultural land from urbanization or managing the conflict between informal urban growth while meeting the demands of the communities. Third urban research symposium on Land Development, Urban Policy and Poverty Reduction. Brasilia, DF, Brazil: World Bank Institute of Applied Economic Research (IPEA).

[51] Taher Osman, Takafumi Arima, Prasanna Divigalpitiya.(2014). Tale of Slums in Cairo Region: Describing the actual gap between the unplanned and planned urban growth in the greater Cairo Metropolitan Region, journal of Habitat engineering and urban design Vol 6. No.1, 83-93.

[52] Nelson, R. F., 1983, Detecting forest canopy change due to insect activity using Landsat MSS. Photogrammetric Engineering and Remote Sensing, 49, 1303-1314.

[53] Tang, J., Wang, L. and Zhang, S., 2005, Investigating landscape pattern and its dynamics in Daqing, China. International Journal of Remote Sensing, 26, 2259-2280.

[54] Thapa, R. B. and Murayama, Y., 2008a, Spatial structure of land use dynamics in Kathmandu Valley, In The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, J. Chen, J. Jiang and A. Peled, (eds.), ISPRS XXI Congress Proceedings, XXXVII(B8), pp. 11-16, Beijing: Organising Committee of the XXI International Congress for Photogrammetry and Remote Sensing.

[55] Frohn, R. C., 1998, Remote Sensing for Landscape Ecology, New Metric Indicators for Monitoring, Modeling, and Assessment of Ecosystems. Florida: Lewis Publishers.

[56] Petit, C., Scudder, T. and Lambin, E., 2001, quantifying processes of land-cover change by remote sensing: resettlement and rapid land-cover changes in south-eastern Zambia. International Journal of Remote Sensing, 22, 3435-3456.

[57] Longley, P. A., 2002, Geographical information systems: Will developments in urban remote sensing and GIS lead to "better" urban geography? Progress in Human Geography, 26, 231-239.

[58] Murayama, Y., 2004, American influence on Japanese human geography: a focus on the quantitative and GIS revolutions. GeoJournal, 59, 73–76.

[59] Thapa, R. B., Kusanagi, M., Kitazumi, A. and Murayama, Y., 2007a, Sea navigation, challenges and potentials in South East Asia: An assessment of suitable sites for shipping canal in South Thai Isthmus. GeoJournal, 70, 161-172.

[60] Herold, M., Goldstein, N. C. and Clarke, K.C., 2003, the spatiotemporal form of urban growth: Measurement, analysis and modelling. Remote Sensing of Environment, 86, 286-302.

[61] Carlson, T. N., 2003, Applications of remote sensing to urban problems. Remote Sensing of Environment, 86, 273–274.

[62] Thapa, R. B. and Murayama, Y., 2008b, Land evaluation for peri-urban agriculture using analytical hierarchical process and geographic information system techniques: A case study of Hanoi. Land Use Policy, 25, 225-239.
[63] U.S. Geological Survey. Earth Explorer. Available online: http://earthexplorer.usgs.gov.
[64] U.S. Geological Survey. Landsat Bulk Metadata Service. Available online: http://landsat.usgs.gov/consumer.php.
[65] Dubovyk, O., R. Sliuzas, and J. Flacke. 2011. "Spatio-temporal Modelling of Informal Settlements Development in Sancaktepe District, Istanbul, Turkey." ISPRS Journal of Photogrammetry and Remote Sensing 66 (2): 235_246.
[66] Baysal, G. Urban Land Use and Land Cover Change Analysis and Modeling a Case Study Area Malatya, Turkey. Master's Thesis, Institute for Geoinformatics (IFGI), Westfälische Wilhelms-Universität, Münster, Germany, 2013.
[67] Bhatta, B. Analysis of Urban Growth and Sprawl from Remote Sensing Data; Springer-Verlag: Heidelberg, Germany, 2010.
[68] Eastman J.R. IDRISI Selva Manuel; Clark University: Worcester, MA, USA, 2012.
[69] Mozumder, C.; Tripathi, N.K. Geospatial scenario based modelling of urban and agricultural intrusions in Ramsar wetland Deepor Beel in Northeast India using a multi-layer perceptron neural network. Int. J. Appl. Earth Observ. Geoinf. 2014, 32, 92–104.
[70] Lin, Y.P., H.J. Chu, C.F. Wu, and P.H. Verburg. 2011. "Predictive Ability of Logistic Regression, Auto-Logistic Regression and Neural Network Models in Empirical Land-Use Change Modeling _ a Case Study." International Journal of Geographical Information Science 25 (1): 65_87.
[71] Guan, D.J., H.F. Li, T. Inohae, W.C. Su, T. Nagaie, and K. Hokao. 2011. "Modeling Urban Land Use Change by the Integration of Cellular Automaton and Markov Model." Ecological Modelling 222: 3761_3772.
[72] Benito, P.R., J.A. Cuevas, R.B. delaParra, F. Prieto, J.M.G. delBarrio, and M.A. Zavala, 2010. "Land Use Change in a Mediterranean Metropolitan Region and its Periphery: Assessment of Conservation Policies through CORINE Land Cover Data and Markov Models." Forest Systems 19: 315_328.
[73] Li, L., Y. Sato, and H. Zhu. 2003. "Simulating Spatial Urban Expansion Based on a Physical Process." Landscape and Urban Planning 64: 67_76.
[74] Yeh, A.G.-O., and X. Li. 2002. "A Cellular Automata Model to Simulate Development Density for Urban Planning." Environment and Planning B: Planning & Design 29: 431_450.
[75] Cecchini, A., and P. Rizzi, 2001. "Is urban gaming simulation useful?" Simulation and Gaming 32 (4): 507_521.
[76] Portugali, J., and I. Benenson. 1995. "Artificial Planning Experience by Means of a Heuristic Cell- Space Model: Simulating International Migration in the Urban Process." Environment and Planning A 27: 1647_1665.
[77] Sant_e, I., A.M. Garc_ıa, D. Miranda, and R. Crecente. 2010. "Cellular Automata Models for the Simulation of Real-World Urban Processes: A Review and Analysis." Landscape and Urban Planning 96: 108_122.
[78] Couclelis, H. 1997. "From Cellular Automata to Urban Models: New Principles for Model Development and Implementation." Environment and Planning B: Planning & Design 24: 165_174.
[79] Thapa, R.B.; Murayama, Y. Urban growth modeling using the Bayesian probability function. In Progress in Geospatial Analysis; Murayama, Y., Ed.; Springer: Tokyo, Japan, 2012; pp. 197–214.
[80] Pontius Jr., R.G. 2000. "Quantification Error versus Location Error in the Comparison of Categorical Maps." Photogrammetric Engineering and Remote Sensing 66 (8): 1011_1016.
[81] Landis, J.R., and G.G. Koch. 1977. "The Measurement of Observer Agreement for Categorical Data." Biometrics 33: 159_174.
[82] Kubiak, M.; Dzieszko, P. using thermal remote sensing in environmental studies. Trans. GIS 2012, 16, 715–732.
[83] Zawadzka, J.; Mayr, T.; Bellamy, P.; Corstanje, R. Comparing physiographic maps with different categorisations. Geomorphology 2015, 231, 94–100.
[84] Gingrich, P. Introductory Statistics for the Social Sciences. Available online: http://uregina.ca/~gingrich/ch11a.pdf.
[85] JICA (2008). The strategic urban development master plan study for sustainable development of the Greater Cairo region in the Arab Republic of Egypt.The final report summary, volume 1. Cairo, Egypt.

7. Modeling urban change scenarios for 2035 Focusing on the middle sector of Giza area by using SLEUTH model

∗ This chapter is based on the following paper:

Osman, T., Divigalpitiya, P. & Arima, T., 2016. Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on land use in the Giza Governorate, Greater Cairo Metropolitan region. International Journal of Urban Sciences, pp.1–20. Available at: http://dx.doi.org/10.1080/12265934.2016.1216327.

Abstract

The goal of this paper was to find an appropriate urban policy to preserve arable land that is being consumed by highly accelerated urban growth in the Giza Governorate of the Greater Cairo metropolitan region for the last 50 years. We simulated three different urban policies and relevant growth scenarios for Giza from 2015 to 2035 by using the SLEUTH model to investigate their effects on arable lands. The first scenario was historical growth trends to simulate the persistent growth trends under existing conditions. The second was a compact growth scenario with robust restrictions on development in the areas that are outside of designated growth centers. The third scenario was officially planned growth that integrates stricter growth plans and stronger protections on natural resource lands at a level that could be realistically accomplished with strong political commitments. The input data required by the model, including slope, land use, exclusion, and urban growth, transportation, and hill shade were derived from three Landsat satellite images from 1984, 2000, and 2013 according to supervised classifications. The simulation results found the compact growth policy scenario had the least negative impact on arable lands while the historical growth scenario had the worst impacts.

Keywords: Informal urbanization, development policies, spatial modelling, transportation networks, developing countries.

7.1 Introduction

During the past five decades, Egypt faced an unprecedented urbanization process, despite all governmental efforts to slow it down. Despite having less than 10% of the total urban population at the beginning of the 20th century, the proportion of the urban population had reached 45% by the end of that century. The annual growth rate of the urban population in Cairo is projected to be 2.2% until 2050, which exceeds the 1.8% annual growth rate of the entire population [1]. Egypt's urbanization started in the 1950s and continued to develop beyond the plans for it, driven by informal market forces. Informal areas grow particularly in villages and small towns, but will also continue to grow in big cities such as the Greater Cairo Region and Alexandria. The Nile Delta is, in itself, a booming urban agglomeration. It is perfectly located for international markets and will attract more and more people in the future.

Taher et al., 2014 [2] noted that the informal growth areas in the GCMR grew by 3.4% per annum between 1991–1998 while their population increased by 3.2% per annum. MOP and GTZ, 2004 [3] estimated that the erosion of arable lands, since 1980, has been one million acres or 12% of the total agricultural land in Egypt. El-Hefnawi, 2005 [4] estimated that the cost of arable lands converted to informal areas was around US$46.2 billion, in addition to US$63.1 billion—the cost for informal buildings over arable lands. In our case study of the Giza governorate, the western part of the GCMR, the urban area has increased by 135.34% between 1984 and 2013. During the period of 2004–2013, the urban area increased by 44.47%. Growth in the eastern part of the GCMR was only 13% in the same period. This urban growth has continued outside of urban planning regulations and consumed 12,733 ha of high quality cultivated lands between 1984–2013. Urban growth causes loss of productive agricultural lands and other forms of greenery, loss in surface water bodies, reduction in ground water aquifers, and increasing levels of air and water pollution [2,5,6].

The government's efforts to manage urbanization to prevent informal urban growth started earlier in the middle of the 1950s. On one hand, to keep the built environment, the government started to create the first urban development plan for the GCMR in 1956, then followed that with new plans in 1973, 1982, 1991, and 2006 [7]. However, the accumulated governmental plans failed to prevent the growth of informal areas. On the contrary, they had serious negative results and made the informal sector the predominant channel for providing shelter to the urban poor [8, 9]. Nowadays, the GCMR has more than seven million inhabitants living in informal areas; 80 percent are on privately owned arable lands. The informal growth areas have expanded, particularly onto private arable lands, and less frequently onto publicly owned desert land. According to the UNDP's figures, 2004 [1], by 2025 around 50 percent of Egypt's urban population is anticipated to live in informal growth areas. On the other hand, the governmental efforts to preserve agriculture lands started in 1966 through command and control policy tools. However, most of them were focused on regulatory instruments to protect the agricultural land regardless of the reasons behind urbanization.

In 1982, Law No. 3 regulated all transgressions and stipulated that agricultural lands should be taken into consideration in the process of urban planning; it designated certain areas for specific types of use. In 1983, Law No. 116 became the main arm of policy to protect agricultural land. This law totally prohibited any building construction on agricultural land. In 1994, Law No. 4 stipulated that development should not take place on prime agricultural land. In 1996, the government completely banned the development of agricultural land and made it a crime. Lastly, JICA, 2008 [9] decided that the agricultural lands outside of the central core of the GCMR should be completely protected and should not allow any urban development activities. Moreover, the government in the 1980s started to build the ring road around the main core of the GCMR to stop the urbanization of arable lands and reduce Cairo's traffic. However, it failed to prevent urban growth. The construction of the ring road has put extensive pressure on land prices, which made it uneconomical, from the farmers' point of view, to continue farming owing to the enormous increase in land value. The ring road increased the prices of the surrounding agricultural land by ten times in the past 20 years [10].

Consequently, to overcome the problems related to urban growth, new urban policies should be formulated for better urban forms that can help to sustain development, especially to minimize unnecessary agricultural land loss. Yeh, 2002 [11] gave four conditions for how future urban patterns could be made sustainable. First, too much agricultural land at the stage of early development should not be converted. Second, the amount of land consumption should be determined based on the availability land resources, and population growth. Third, urban growth should be guided toward sites that are less significant for food production. Lastly, compact growth patterns should be considered as the most favorable pattern for future development.

SLEUTH is a Cellular automata model which uses the Monte Carlo method for calibration (random values) to derive a set of coefficients that can predict future states [12]. Then, for the prediction stage, SLEUTH uses Cellular automata mathematical models for complex natural systems which contain large numbers of simple, identical components with local interactions [13]. The pioneering study by Clarke et al., 1997 [14] in California, found that the SLEUTH model achieved significant success in simulating urban growth on a regional scale. It was then applied in various studies [15-19]. The SLEUTH model provides a decisive representation of one of the main parameters influencing urban growth—transportation networks [20,21]. Clarke and Gaydos, 1998 [12] used the Urban Growth Model (UGM) to create long-term urban growth predictions for the San Francisco urban area. Also, Jantz et al., 2003 [22] used the same model to assess the influence of future policy scenarios on land use in the Baltimore–

Washington metropolitan area. In that research, the SLEUTH model was used to project the extent of urban growth under three policy scenarios: current trends, managed growth, and ecologically sustainable growth. The SLEUTH model was selected in their project because of its easy operation, its ability to integrate different protection levels for various areas, and its simple combination with raster GIS.

Yang and Lo, 2003 [23] used SLEUTH to predict urban growth and to find the influences of various policy scenarios in the Atlanta metropolitan area. They identified SLEUTH as an effective tool to imagine, test, and choose between possible urban growths scenarios in relation to diverse development and environmental conditions. Herold, Candau, and Clarke, 2003 [24] used SLEUTH to identify the consequences of war, economic booms and crashes, technical innovations, and disasters on future urban growth. Xiang and Clarke, 2003 [25], and Nassauer and Corry, 2004 [26] said that the scenario design process is crucial for the SLEUTH model to identify better urban patterns for future urban growth. Detailed, contrastive, divisive, and scientific scenario designs affect the results. Scenario design is a significant parameter of urban growth models such as SLEUTH, which determines whether we can envision the future alternatives of urban growth patterns and their potential influence. Data spatialization and attainability are significant for integrating various policies [27]. We combined urban growth policies, land-use data, and environmental protection regulations into the scenario designs.

In GCMR, no previous attempts were made by researchers to study urban growth at the expense of agricultural land, except for one undertaken by Abd-Allah, 2007 [28], who tried to predict future urban growth in the GCMR. However, the simulation attempt failed to test the effectiveness of GCMR planning policies which were thought to hinder future urban growth within the GCMR. Moreover, in 2008, the general organization of physical planning (GOPP) submitted the final authorized development plan for GCMR [9] determining the major growth directions in the whole region until 2035. The 2008 GCMR plan completely changed the growth parameters which Abd-Allah, 2007 [28] used in the urban growth scenarios for Giza 2027. In addition, the new GCMR plan included a new classification of agricultural land-protection decrees, which determined priorities for urban growth in the Giza governorate. In this paper, we use the SLEUTH growth model to simulate the effect of different development policy scenarios on urban growth in Giza, which is the area in the GCMR most affected by informal growth. We used the SLEUTH model because it is dynamic, scale independent, and future-oriented, as well as compatible with the crucial requirements of our urban growth simulation policies. The model can also adjust itself if large-scale growth leads to disparity from the normal linear growth, which is the favorite for creating a reasonable growth forecast. The behavioral rules guiding growth in SLEUTH consider not only the spatial characteristics of neighboring cells but also the extent of the existing urban spatial expanse, and transportation networks [29]. Moreover, SLEUTH's design permits it to be used in diverse regions with diverse datasets, which can save time and labor in programming.

The goal of our study is to predict future urban growth both spatially and temporally by using the SLEUTH model, and then analyze three alternative planning policies as possible growth scenarios; by modeling their effects on future urban growth, planning actions that can help in controlling and hindering future informal urban growth in the form of "what-if" analysis can be tested. Moreover, we are trying to propose and simulate our own policy (compact growth scenario), which meets the previously mentioned requirements for sustainable form, and assess its effect in 2035 by the SLEUTH model; this will allow comparison of its effect with the official governmental policy of growth, and measurement of the differences between the two, to find the best direction for future growth in the GCMR.

7.2 Data and Method

7.2.1 Study Area and Data

The study area is situated at latitude 30° 06′ N and longitude 31 28′ E. The region is situated in the east of the River Nile south of the Nile Delta. It is bordered from the west by the urban area of the Giza governorate on the western banks of the River Nile (Figure 7.1). The region is demarcated by the El Moqattam hills to the southeast, and desert areas on the eastern borders. The southern border of the Governorate of Qalyubia, which is the northernmost reach of Greater Cairo, borders Cairo from the northwestern side. The Cairo region includes part of the Nile Delta arable land and the River Nile from the west and the bare desert lands of the east. Cairo has a wide diversity of urban characteristics, such as a central business district, high-class residential areas, low-class residential areas, and unplanned areas. All of these divisions have high building and population densities. All of the districts in Cairo are mixed with commercial, public, and sometimes industrial uses within the same block. However, variations can be identified easily between high-class residential areas with a lower density of population (6,300 people/km^2); low and middle-class residential areas with higher density; and informal urban areas (44,800 people/km^2). The location of our research area is shown in Figure 7.1 located in the eastern part of Greater Cairo, part of the Giza governorate with a length of about 18 km and width of 15.5 km. The area covers about 279 km^2 (27,900 hectares) and involves diverse land uses and urban densities.

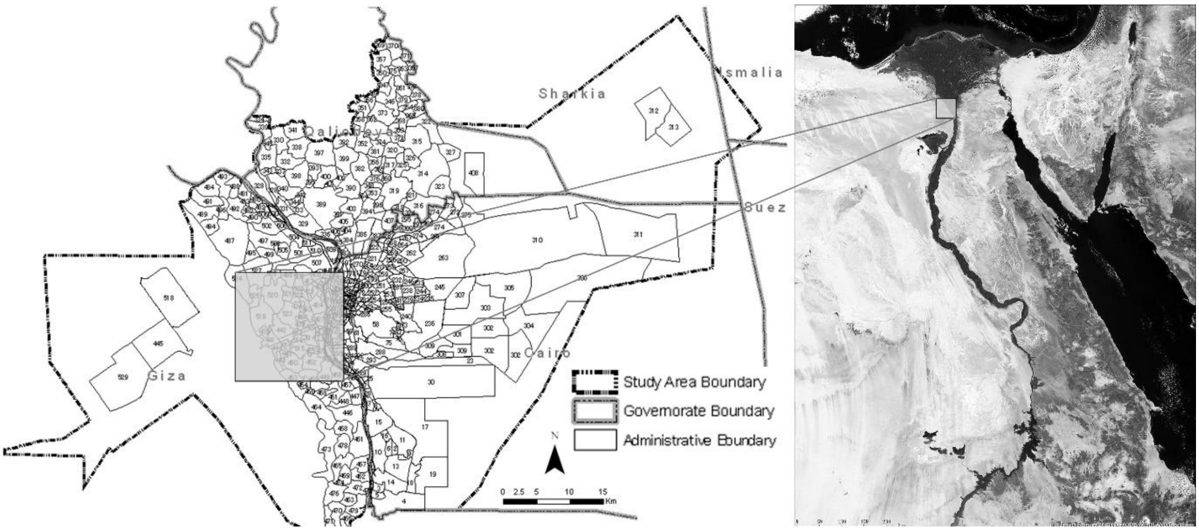


Figure 7.1 The study area

The primary data in this paper are three Landsat TM and ETM images from 1984, 2000, and 2013. Table 7.1 lists the SLEUTH model data requirements and generation methods. To accomplish the input prerequisites of the model, supervised image classification was achieved from which to derive land-use maps and urban growth. In support of ArcGIS 10.1, a topographic map was utilized to set up a digital elevation model (DEM) for generating the slope map, hill shade background and watershed boundaries. Road networks were derived from the satellite images through referencing three regional road maps of 1984, 2000, and 2013. For the calibration stage, the excluded layer was comprised of water, which was totally excluded from development, as well as historical sites, protected areas, and local parks. All the data layers were referenced to the same Universal Transverse Mercator coordinate system and sampled to the same pixel resolution of 120 m to reduce the size of the array while preserving the spatial growth of the study area and the capacity to check for overlay accuracy. Because SLEUTH needs a binary representation, these continuous data were converted into an 8-bit grayscale image in GIF format.

Table 7.1 Data requirements for SLEUTH Modeling

Input layers	Data requirement	Extraction
Slope	One slope map	Derived from DEM
Land use	In this paper three land-use maps were utilized to raise the calibration accuracy	Supervised image classification of Landsat TM images of 1984, 2000, and 2013
Exclusion	One map depicted the area that cannot be developed	Definition according to interpretation of planning scenarios
Urban growth	Three periods of urban growth for calibration	Extracted from TM images through image classification
Transportation	This paper utilized three road network maps	Derived from images with support of three region road maps of 1984,2000, and 2013
Hillside	Background for display purpose	Derived from DEM

Image classification was employed to classify and improve Landsat TM and ETM images in bands 1–5 and 7. The utilized scenes contain a wide range of land-use types, including urban, desert, vegetation, and water, with high reflectance levels. An advance classification matter was the impediment in spectrally differentiating desert and urban features, perhaps owing to the thick layer of sand that covers urban features. Although many improvements, band combinations, and ratios were investigated, an automated relative reflectance improvement—known as internal relative reflectance (IARR)—finally showed the most efficacious algorithm that was appropriate to both images. Kruse, 1988 [30] described the IARR algorithm by its ability to normalize the pixel values to the average scene spectrum and render new pixel values as relative reflectance thereby removing most of the atmospheric effect. The improved images were then subject to unsupervised classification using 40 classes, which approximate the number of classes extractable without important overlaps. The classified images were then recoded into eight classes: urban features, water, vegetation, desert, urban/water mix, urban features/vegetation mix, and urban/desert mix. Ground-truth points were identified and field-tested in November 2014. The mixed classes that comprise more than just one land cover type reflected the complexity of land-use patterns in the Giza area. For instance, the pixels of urban features/vegetation mix are typically found along the interfaces of urban cores, although some of the pixels of urban features/desert mix are composed of urban built-up surfaces made of building material from the nearby deserts.

7.2.2 Modeling Approach

The SLEUTH model (slope, land use, exclusion, urban growth, transportation and hillshade), is a development of the UGM, established for the first time in 1998 by [12]. It is built in two different modules, which can be operated autonomously: the UGM, which simulates urban growth, and a Land Cover Model, that allows for monitoring the alterations in land use. In its major module, SLEUTH is a probabilistic model with Boolean logic. This approach employs brute force calibration according to the study of parameters in decisive ranges which are gradually decreased. This model can be used to explain different phenomena in different areas by adjusting parameters potentials. Consequently, there is not any limit in the size of the research area. There are case studies about an entire region and applications for a single city. SLEUTH predicts urban growth, according to a diversity of growth rules to do with the type of urban cells, the interaction of urban cells, and their environment [12]. It is carried out in two general stages: the calibration stage, where the model re-uses historical development trends, and the prediction stage, where historical trends are directed into the future. This lets the model use known historical circumstances and helps in grasping the different values in a probabilistic way [12].

The time unit of the growth simulation is the growth cycle, which corresponds to one year. Urban growth dynamics in the UGM module, which supplies probabilistic information, are modeled using four sequential rules: spontaneous new growth, organic newly spreading centers, diffused edge growth, and road-influenced growth. All the cells that compose the entire automata are upgraded on the entire grid after each rule application. These are utilized during each growth cycle and controlled through the interactions of five growth parameters: dispersion, breed, spread, road gravity, and slope. The first five parameters affect how the transition rules, which depict the growth and alteration of the region, can be utilized. The five parameters shown in Table 7.1 depict the growth pressure in the urban system. Resistance to growth is integrated through the slope resistance parameters, and through a user-defined excluded layer, which includes areas such as water, parks, or restrictive zoning that are eliminated from development.

To simulate different scenarios by SLEUTH, three methods could be utilized. The first is changing the parameter values that affect urban growth rules, and consequently determining the pattern of urban growth [31]. The second method is to find different levels of protection values for specified areas in the excluded assigned layers [32]. The third method is by manipulating the self-organization constraints [23]. In this study, we used the first method of changing the parameter values because of its flexibility. For the historic growth trends scenario, we used 11, 13, 49, 2, and 43 for diffusion, breed, spread, slope, and road gravity. This combination supposed that the current status would be maintained and the future growth would occur according to the historical trend. In the compact growth scenario, we reduced the spread and breed parameter values to half. These parameters mainly describe the trend of urban growth and the effect of road gravity on the growth of urban settlements near the road networks.

7.2.3 Calibration

Calibration was accomplished in the SLEUTH modeling environment through a Monte Carlo (MC) method. For the computational prerequisites of this approach, calibration was operated in three stages: coarse, medium, and fine. For each set of parameters, simulated growth is matched with real growth using several least squares regression measures, like spatial coincides, urban cluster edge pixels, and other fit statistics. For each group of parameter values in an MC reiteration, the model computes these measurements then averages them over the group of MC reiterations, and matches these to measurements computed from the real historic data to output least squares regression measures. The Lee-Sallee metric is utilized to calculate spatial fit. After each calibration stage, the top group of comparison values specified the range of scores utilized in the subsequent stage of calibration. Descriptive statistics were computed for the group of top values to determine suitable growth that would be utilized in the next stage of calibration.

The target of calibration is to derive a group of scores for the growth parameters that can effectively model growth during the historic time period, in this case, 1984–2013. For calibration, the earliest urbanized area data of the year 1984 is utilized as the seed. Related urban layers, or control years 2000, and 2013, were utilized to statistically compute best-fit values. Then the simulation was carried out using the historical data to anticipate urban growth in 2013, which was already known. The group of parameters derived from the calibration was utilized to predict future urban growth, permitting the model to use equivalent known historical circumstances, as long as they helped in grasping the significance and density of the different values probabilistically. One hundred MC reiterations were operated, and a map that manifested the probability of any given cell becoming urbanized by 2013 was created. The simulated map of urban growth in 2013 was matched with the mapped 2013 growth.

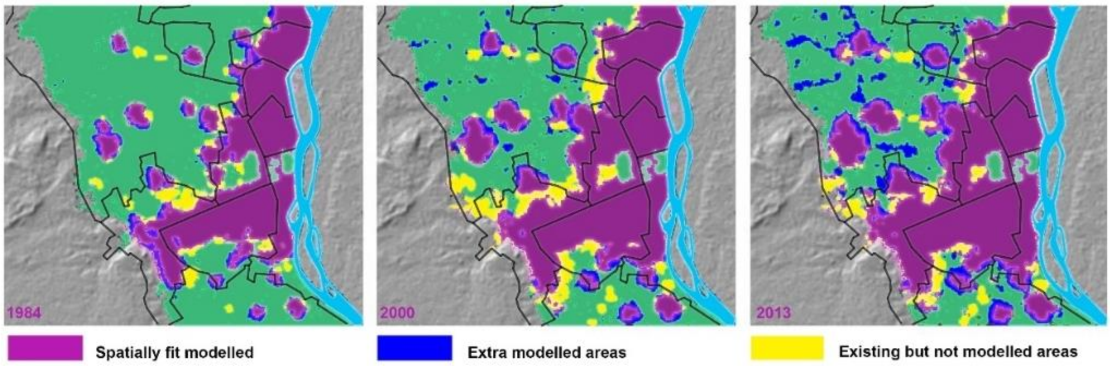
7.2.4 Prediction

Urban growth prediction is the most significant application of the SLEUTH model. Based on the needs identified, different scenarios can be prepared to predict the future growth of the region. This paper, in the model prediction of the latest urban growth dilemma for the base map layers, uses the final correct scores for correction through the 100 MC; it does so to examine the probability of future urban plans, inclusive of the urbanization probability of more than 90% of the cells as predictions of urban land use. To derive various scenarios of urban growth in layers, over the predictions, they can be grouped into various basic circumstances. Three future growth scenarios were simulated: historical growth trends, compact growth, and officially planned growth. The excluded layer served as the primary tool to distinguish between the three plan scenarios, but various future transportation networks were also created and integrated into the model in 2035. In addition, the input image of urban growth was changed to comprise developments established for the future in the historical growth trends scenario.

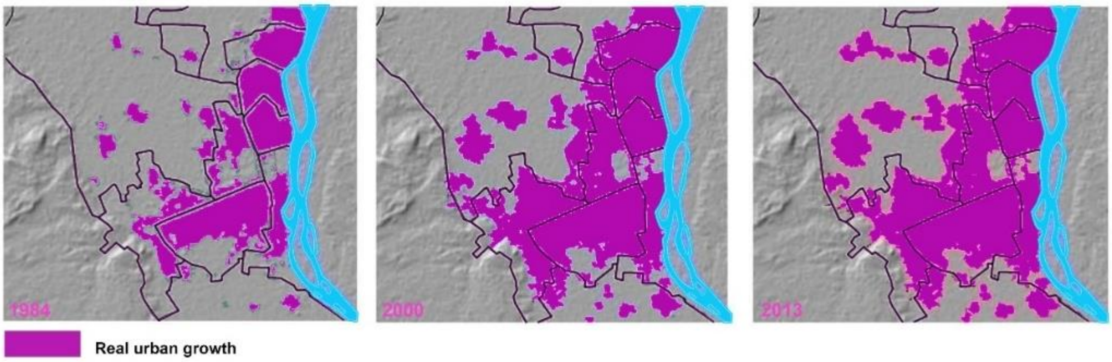
7.3 Result

7.3.1 Calibration

After precisely checking various parameter groups according to various fit statistics, we established that the parameters according to the comparison metric were fit to identify the value of growth that occurred in the system, and were also fit to simulate urban forms effectively, as proved by the high value (all scores above 0.53) for the Lee-Sallee metric. Consequently, we utilized the comparison metric as the primary fit statistic throughout the calibration process. The dispersion and breed parameters were the most variable throughout the calibration process, and thus have higher ranges and coarser steps. After the fine calibration, the final parameter scores that created the highest score for comparison were submitted in Table 7.2. These parameter scores specified the growth trends that were utilized to predict future development types.



(a) Simulation



(b) Reality

Figure 7.2 Urban growth simulation versus reality in Cairo from 1984 to 2013 (a) Simulation (b) Reality

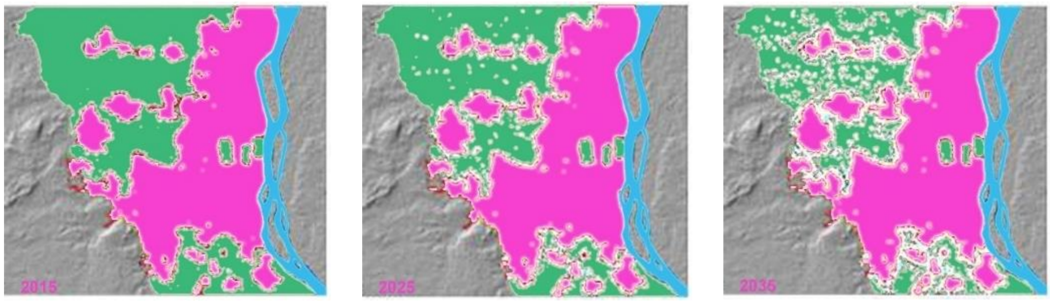
Table 7.2 Results of the coarse calibration step

Index\Step	Coarse	Fine	Final
Compare	0.847	0.886	0.876
r2 Population	0.763	0.787	0.826
Edge r2	0.851	0.862	0.883
R2 cluster	0.858	0.873	0.887
Leesalee	0.553	0.576	0.558
Average slope r2	0.604	0.625	0.607
% Urban	0.568	0.565	0.557
X_r2	0.881	0.89	0.888
Y_r2	0.878	0.876	0.883
Radius	0.75	0.77	0.80
Diffusion	6	8	11
Breed	8	11	13
Spread	37	41	49
Slope	1	1	2
Road gravity	31	35	43

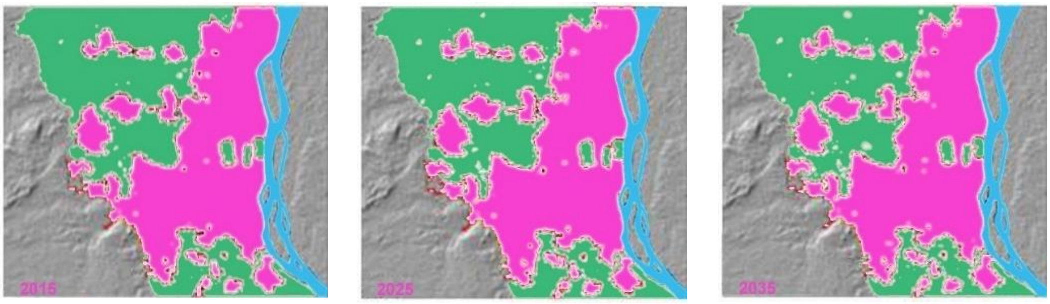
After the calibration, urban growth and renewal actions can be simulated. The simulation is helpful to understand the self-organizing urban characteristics, and identify the techniques and reasons of urban growth more extensively. Using the final parameter scores above, the urban growth simulation of Cairo from 1984 to 2013 is rebuilt with a statistical degree of match in Figure 7.2. The overall spatial accuracy at the pixel scale was high enough (87.6%). The outputs of the spatial accuracy assessment detect that the model can simulate local types of urban development as well. Monitoring the calibration outputs, we can detect that the spread and road growth parameter values are higher, which clarifies that the urban growth is, at most, from the centers to the fringes, as well as along the transportation networks. The low dispersion value signifies that the phenomenon of spontaneously forming urban spots in low-density areas is not clear.

7.3.2 Prediction

Historical growth trends scenario



Compact growth scenario



Growth as officially planned scenario

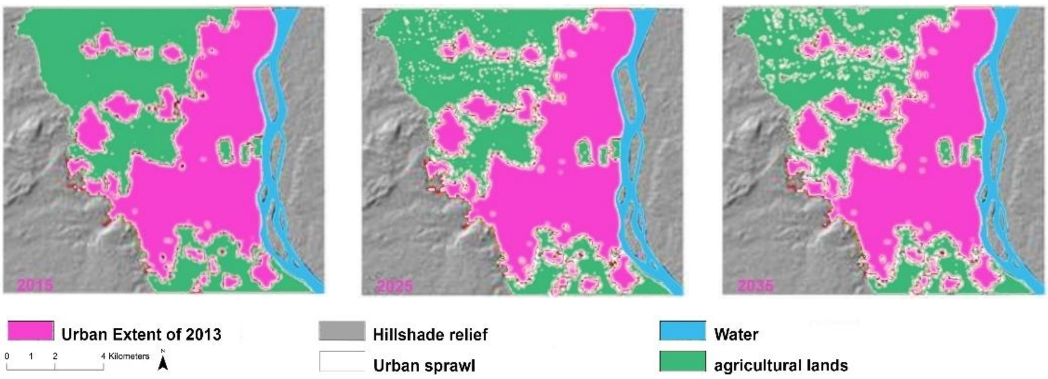


Figure 7.3 Urban growth scenarios in Cairo

Besides simulating reconstruction of urban growth, the SLEUTH model can also spatially identify the urban growth types in the near future under various urban land-use planning policies. This implies that some urban land-use planning plans can be tested and identified to help us further grasp the urban growth in Cairo. Three future growth scenarios were simulated: historical growth trends, compact growth, and officially planned growth, with the excluded layer serving as the primary tool to distinguish between the three plans scenarios; however, various future transportation networks were also created and integrated into the model in 2035. In addition, the input image of urban growth was changed to comprise developments determined for the future in the historical growth trends scenario.

A. Historical growth trends scenario

The first scenario assumed that the historical growth trends would continue if the developmental circumstances do not change. Consequently, this scenario may be termed "historical growth trends." The model was utilized to simulate the spatial outputs for this scenario with almost the same basic circumstances as those utilized in the past for the present simulation. The only distinction is that the 2013 urban growth data are utilized. This scenario assumed the permanence of urban growth as the factor for unaltered and sustained growth. Consequently, it provides one criterion for comparing alternative growth plans. The study area simulated urban area for 2035 would be about 108.8545 km^2. The net growth of urban land between 2015 and 2035 would be about 20.458 km^2. The simulation identified a 23.14% rise in the urban area in comparison with the basic area in 2015. As an output of such growth, the urban land would be about 31.5% of the total agricultural land in the study area by 2035.

The number of urban clusters would reduce from 215 in 2015 to 151 in 2035. This implies that smaller urban clusters would extend to the outward fringes and merge together to form larger clusters, thus the reason for the decreasing area of agricultural lands in the Cairo region. The clear alterations predicted for the next 20 years can be identified very well from the model's visual outputs for a single year. By assessing these graphical results precisely, it was found that by approximately 2035, villages like Kirdasah and Nahya would be merged together and this unified area would form a basin of agricultural land together with the major urban core of the Cairo region. The output will be a huge urban area that encircles agricultural lands that will soon vanish because of future urban growth. The graphic images also show that the agricultural lands encircled by the ring road will be totally urbanized by the impact of organic growth and road-influenced growth.

B. Compact growth scenario

This scenario assumed slowing down the urban growth rates and changing the patterns of growth while preserving the livability of the region. The model is utilized to simulate the spatial outputs of this scenario with the environment and development circumstances given in Table 7.2. The projected future urban growth predictions for the other two scenarios show that 68.3% of urban growth is occurring by organic growth, while the road-influenced pattern is 28.4%. Spontaneous and diffusive growth contributed 3.3%. The compact scenario prevented the organic and the road-influenced growth but supported the other two types of growth. In addition to the road-influenced growth, the growth of existing urban cells into their surroundings should be reduced. Otherwise, the development of urban settlements in undeveloped areas (spontaneous growth and diffusive growth) should be increased. Accordingly, more formal residential growth should be supported in simulations, and more control over unplanned growth should be conducted. To fulfill this concept in the simulation, some parameters were changed. The starting value of the spread coefficient was decreased by 35% to 26. In addition, the road influence coefficient was decreased by 15% to 33 given that the road-influenced growth accounted for only a very tiny share of total growth in the past two scenarios. The diffusion and breed coefficients were raised to 40 (about 72%–78% respectively).

In the hope of encouraging more development within the new boundaries of the existing villages surrounding the Giza area, the exclusion probability was set to 30% (a 70% urban growth probability). The exclusion probability was set to 55% (a 45% urban growth probability) within the boundary of the ring road, to fulfill more constraints on the urban development of the remaining agricultural lands inside Cairo's regional borders. Otherwise, the exclusion probability was raised to 80% (a 20% urban growth probability) in the surrounding area of the Cairo region, (other than the new village's boundary and the area bounded by the ring road), to strictly prevent growth into agricultural lands. Based on this scenario, the predicted urban land for 2035 was about 96.55 km2. The net increase in urban land from 2015 to 2035 was 8.154 km2, indicating an increase of 9.22% in comparison with the basic area in 2015. By 2035, the urban land would be about 12.58% of the total agricultural land in the study area by 2035. The number of urban clusters was 186 in comparison with 215 in 2015.

C. Growth as officially planned

The third scenario considers future road developments and environmental protection while other circumstances used in the first scenario are still valid. This offers an alternative growth plan in which protection of the environment is highly supported so that the region is more habitable. In this scenario, the plan proposed by the GOPP in 2008 is comprised of some new and upgraded roads including the Northern arc, which is equivalent to the current major road that starts from the ring road to the 6th of October City in the Giza governorate. A new roads layer was added, with this upgraded information, for the year 2015. Environmental protection is another significant concern in urban development planning in the Cairo area. Water conservation is also a crucial issue for clean water supply. Consequently, the protection of canals found in this area, is a key step toward achieving this target.

To fulfill this concept in the urban models, some buffered zones were created along main canals in the study area. These buffered zones cover areas of 75–150 m-wide strips from the centers of these canals. Various probabilities exclusively for urban development are assigned to these buffer zones. The buffer zone within 75 m is assigned a value of 100, meaning that this area is not permitted at all for urban development; the buffer zone between 75 and 150 m is assigned a value of 60, indicating a 50% probability of exclusion. Then, these buffered zones are integrated with the existing layer of excluded areas to produce a new file for the urban simulation outlook under this scenario. Besides the conditions applied in the first scenario, the third scenario uses one more "roads" layer (2015) and an upgraded layer of excluded areas. Under this scenario, the predicted urban area for 2035 was about 100.92 km^2. The net rise in urban land from 2015 to 2035 was about 12.532 km^2, indicating an increase of 14.17% in comparison with the basic area in 2015. By 2035, the urban land will be about 19.34% of the total agricultural land in the study area by 2035. The number of urban clusters would reduce from 215 in 2015 to 157 in 2035.

7.4 Discussions

7.4.1 calibration

This study used the SLEUTH model to investigate the urban growth mechanism and to evaluate three alternative scenarios in a flat surface agriculture environment. The best-fit values of five growth coefficients are shown in Table 7.2. The diffusion coefficient is in the center, which reflects an average likelihood of dispersive growth. The low value for the breed coefficient reinforces it, given the low growth probability of new urban settlements. Moreover, the calibration shows that the major growth modes in the study area were spread and road gravity. That is, new developments tended to appear either at the edge of existing urban areas or around major roads. The high spread coefficient means that the predicted mode of growth in Giza is organic or edge growth. The very high value of the road gravity coefficient denotes that the growth occurring along the main roads is also extremely influenced by the transportation network. The very low value of slope resistance affects the lower influence of slope to urbanization. In the Giza area, topography had only a very small effect in controlling urban development.

The subsequent growth tends to agglomerate around existing urban cores for better production organization and service delivery [2]. Thus new developments usually took place contiguous with existing area (spread) around major roads (road gravity). Moreover, newly urbanized patches became the growing poles (breed) at a lower rate. This also explains why specification of setting growth limitations to small patches has largely restricted urban development in the second and third planning scenarios. In fact, contiguous development and infill development were common in the study area, also indicating the disregard for planning regulation constraints on availability of infrastructure.

In the calibration process, it was not only possible to simulate the evolution of our study growth areas, but it also allowed for identification of the different characteristics of urban evolution, as seen in the Lee-Sallee score. This score identified the degree of shape matches between the modeled growth and the known urban growth for the control years; if the model is in different intensities, this index will reflect that. The shape index had a value of 0.558 in the Giza area. It is very hard to get high values of shape match in the index of Clarke and Gaydos ,1998 [12], and a value of 0.558 is fairly good for our case study. The much defined shape of the growth areas in Giza makes it hard for the model to fit the actual shape exactly. Also, Giza has scattered urbanization, making it harder to define many particular forms at this scale except by scattering pixels of growth all over. The comparison with other research findings shows that their Lee-Sallee value is equal or lower than in the Giza study area. For example, the Lee-Sallee value was 0.3 in Washington/Baltimore [12]. In Lisbon, the Lee-Sallee value was 0.35, and 0.58 in Porto [15]. The Lee-Sallee value was 0.347 in Isfahan [33], 0.36 in Mashhad [34], and 0.59 in Karaj [35].

For the model parameters, the spread parameter in Giza was 49, which shows that the probability of edge growth is quite high; this is not consistent with the findings of Tan et al. ,2009 [36], or Bihamta et al. ,2014 [33]. However, there are some similarities in their urban characteristics and the Giza area. So, the possibility of the edge urban growth pattern of the existing urban centers is highly likely to happen in the study area. This high probability and high likelihood of spread are believed to be responsible for some of the dispersive urban growth in the Giza area. The relative importance of the coefficients shows moderate variations in which spread parameter is quite prevalent. Consequently, similar to other findings [33-40] , the area is expanding along its current boundaries and growing toward its immediate surroundings.

The second significant factor in the Giza case study was the road gravity coefficient (43). This factor, which is similar to other findings, causes road-influenced growth and can control an important part of Giza growth [22,33,34,36,40-42]. Thus, it emphasizes a linear growth type based on road infrastructures, which signifies that building transportation networks and infrastructure facilities affect any further establishment of urban growth in Giza. However, our findings showed a high degree of difference between the current application of the SLEUTH model and the results of the pioneering studies conducted by Silva and Clarke, 2002 [15], and Yang and Lo, 2003 [23] about the importance of the road gravity coefficient in directing urban growth.

On the other hand, the value of the diffusion parameter was 11, which is low compared to other parameters in the Giza area. Thus, the eventuality of spontaneous growth is low, too. The low diffusion parameter shows that Giza has an outlying form of growth with its main urbanization occurring near the existing urban cores. We found that occurrence of the new urban centers near the main city center through spontaneous growth has a low probability. Moreover, the low value of the diffusion coefficient is in accord with the studies carried out by Gandhi and Suresh, 2012 [43], and Bihamta et al., 2014 [33] owing to the similarity in some urban characteristics. This may be clarified by the factors of urban development where there are available lands with suitable conditions, which were inconsistent with the findings of other research [34,35,38,40,44] because of some differences in their urban attributes. In addition, the breed coefficient scored 13, which shows that the probability of new spreading center growth happens infrequently in the region. The value of the breed coefficient is followed by the diffusion parameters, which is consistent with the findings of Dadashpoor and Nateghi ,2015 [44], and Mahiny and Clarke ,2013 [39]. However, it is inconsistent with the findings of others [33- 35, 38, 40].

The flat agricultural lands in Giza's environment established slope resistance as the lesser factor with a coefficient value equal to 2, which implied that topography was not a limiting factor for urban growth in Giza. This fact was confirmed by field checks and current data on new growth areas. This natural environment supported the edge growth in Giza in all directions. Thus, edge growth and linear growth are the principle patterns in this area (Figure 7.3). According to the value of the slope resistance coefficient, this study shows a high degree of consistency to other cities with the same topographic characteristics where the SLEUTH model is applied [22,34,42]. When comparing results of the current study with others [33-35, 38-40, 44, 45], partial differences are found owing to the nature of topographic characteristics. Steeper slopes completely stopped urban growth in these cases and they are considered a constraining force, as reflected in the slope resistance coefficient that scored a high value in these studies.

7.4.2 prediction

The 2015–2035 modeling of growth scenarios shows that in the historical growth trends scenario, the increase in urban areas within the study area will be about 20,458 km^2, while in the officially planned growth scenario, the expected increase in urban areas will be about 12,532 km^2. The compact growth scenario will save about 12,304 km^2 of prime agriculture lands compared to the historical growth trends scenario, and 4,378 km^2 of land compared to the scenario of officially planned growth. Under the compact growth scenario, the urban area is expected to increase by 8,1254 km^2, which is about 39.71% of urbanized area compared to the historical growth trends scenario. On the other hand, the area of the officially planned growth scenario will be about 61.52% of the historical growth trends scenario. Spatial distribution of the predicted urban growth is shown in Figure 7.3 for all three scenarios. In the compact growth scenario, the value of breed and spread coefficients was decreased and the rest of the coefficients remained the same. Under this scenario, the area will grow from 88.39 km^2 in 2015 to 96.55 km^2 in 2035. The results indicate that the compact growth pattern will save more agricultural land.

The results from scenarios one and three are quite different when compared to those from the compact growth scenario (Figure 7.3). Both historic trends and officially planned growth scenarios have shown similar results, making visual differentiation difficult. However, the compact growth scenario will preserve some buffer zones along the major roads. The historical growth scenario and the officially planned growth scenario illustrate that unchecked urban growth will displace almost 19%–31% of the agriculture lands in our study area. The growth in the urban land as projected under these two scenarios would alter the region's spatial form, especially as the ring road will not play the role of Giza's boundary. Instead, it will be passing through the city center in the future, if the current growth trend continues. In contrast, the compact growth scenario allows 31% more greenness and open space, including buffer zones along main roads. The urban growth rate will be cut by 19% and 31% compared to the historic trends and officially planned growth scenarios, respectively. Therefore, to preserve the productive land, the compact scenario should be the most desirable one for planning future growth in Giza.

By comparing the reality and simulation images in Figure 7.2, those from 2000, have urban areas in the existing situation that are not observed in the modeled area because of the failure of SLEUTH to predict the pattern of edge growth between 1984–2000 around Giza's main urban core where the impact of the urbanization boom—owing to the ring road and the urban projects—came as an input from official governmental policy. That was implied by the high rates of existing urban areas that were not modeled in the images from 2000 compared to the 1984 and 2013 images. The extra area in the modeled zone in 1984 was 2.6% (1.03 km^2) of the total study area and was completely within the pattern of edge growth, while in 2000 it increased to 5.3% (3.05 km^2) of total area in the patterns of spontaneous and edge growth, and in 2013 it jumped to 12.7 % (11.22 km^2) of total area. The extra area modeled was highly concentrated around the small urban centers located in the agricultural lands in 1984. The governmental project of the first ring road around the main core of Giza city attracted a major amount of growth around it, which decreased the potential of growth around the peripheral urban centers. That was a part of the official governmental policy to prevent growth on agricultural lands around peripheral areas through protected zones, and concentrate growth around the main city core. In 2013, the spontaneous growth and new spreading centers growth patterns were considerably diminished as the very strict regulations undertaken by the new governmental policy since 2008 considered these areas as highly protected zones, which meant there was no possibility for supporting infrastructure and basic services for any type of new building. There was little concentration of urbanization around main urban centers and the ring road compared to its previous rates in 1984 and 2000, which could explain the increase of extra modeled areas in 2013 compared to the previous images.

On the other hand, the effect of the ring road around Giza was considerable; it changed the pattern of growth in 1984 from spontaneous to edge growth with the highest-ever growth rates even more than the rates that had been predicted previously, which can be observed in the increase of the existing (but unmodeled) areas in the year 2000 images in Figure 7.2. The existing area represented 4.1% (1.63 km^2) of the total area in 1984 in the spontaneous and edge growth patterns. The model failed to forecast the pattern of spontaneous growth that occurred in this area before launching the first stage of the policy of protecting agriculture lands. In 2000, the area jumped to 11.9% (6.85 km^2) of total area in the pattern of edge growth around the main urban core of Giza city as a response to the ring road's attractiveness in the surrounding zone, while the rest of the non-simulated growth was identified as new areas of spread.

In 2013, the existing (but unmodeled area) decreased to 9.6% (8.48 km^2), which signaled the end of the urbanization boom related to establishing the ring road in the 1990s and 2000s, and the launch of the second phase of governmental policy to protect agricultural lands [9] for the whole GCMR. The new policy phase considered all locations of agricultural lands as protected areas, which reduced the extra modeled zones and concentrated urban growth around major roads near existing urban areas. This had a considerable effect on changing the form of growth to one influenced by roads and edge growth, because land developers searched for the nearest land locations to infrastructure and public transportation. The government started the first phase of agriculture land preservation around peripheral countryside areas by not supporting the peripherals of these areas with infrastructure and basic services. On the other hand, the growth shifted to the suburbs of the main core of Giza city where the possibility existed to extend infrastructure and to use basic existing services.

7.5 Conclusion

The model outputs from the historic trends and officially planned growth simulations demonstrate that small urban clusters will expand outward and merge together to form larger urban clusters. This would change the region's spatial form significantly. The arable lands in our research area will be reduced by approximately 31 clusters or 19% in total by the year 2035 if the existing rate and type of urban growth do not change. The results of the scenario's predictions show higher dispersed development patterns for the historical growth scenario than the official planned growth scenario while the compact growth scenario shows highly constrained growth over the whole region, with most growth occurring in and around existing urban centers. Because of the higher levels of protection, the growth rates for the compact growth scenario were reduced substantially, resulting in much lower pressure on agricultural areas. On the other hand, if historical trends continue, there would be more development, but most agriculture would be lost. Subsequently, the compact growth scenario seems the most effective in limiting urban growth and preserving agriculture.

The study's findings have significant implications for urban planners in the flat surface agriculture environment of urban growth. First, as tiny and isolated urban patches could easily induce new development, freezing growth around these patches could prevent inefficient urban growth. Second, to protect agriculture, setting limitations to urban development around major roads might be an applicable measure. However, there is no optimal solution as urban development and conservation of agriculture are conflicting goals. If the priority is given to development, the historic trends scenario is preferable as it produces the newest urban areas. However, if the priority is agricultural conservation, the other two scenarios are recommended as productive lands are largely protected The plans of local urban municipalities can precede the potential growth areas around existing urban edges, major roads, and proximity to local urban centers as shown in Figure 7.3 by preparing urban plans with strict building regulations to prevent future urban growth being converted to informal settlements. The plans should focus on ensuring support for the potential growth areas through provision of basic services and infrastructure networks. Moreover, the SLEUTH model can be used as a land-use planning tool, providing a visualization process for future urban growth. SLEUTH outputs could be helpful to those who identify urban dynamics, and those who need to both supply services to people living in such swiftly changing environments, and manage natural resources. Thus, GCMR needs a real urban plan, development regulations, and decision support tools for enhancing these steps to decrease growth rates, save productive lands, and conserve the environment.

References

[1] UNDP, 2004. Egypt Human Development Report 2004; major output of the Human Development Project, executed by the Institute of National Planning under technical Cooperation with the United Nations Development Program, Egypt.

[2] Taher Osman, Takafumi Arima, Prasanna Divigalpitiya, 2014. Pseudo urbanization in Cairo Region Measuring urban sprawl with geo-spatial indices, Proceedings of IASUR Conference, University of Tokyo, Japan.

[3] MOP and GTZ, 2004. (Ministry of Planning – German Technical and Financial Cooperation), New Practice of Participatory Local - Development in Egypt's Urban Areas, Policy Paper, Egypt.

[4] El-Hefnawi, A., 2005. Protecting agricultural land from urbanization or managing the conflict between informal urban growth while meeting the demands of the communities–Lessons learnt from the Egyptian policy reforms. World Bank Urban Research Symposium 2005, Institute of Applied Economic Research (IPEA), and Brasilia, Brazil.

[5] El Araby, M., 2002. Urban growth and environmental degradation. Cities, 19(6), 389–400.

[6] Taher Osman, Prasanna Divigalpitiya,Takafumi Arima, , 2016 a, Driving Factors of Urban Sprawl in Giza Governorate of the Greater Cairo Metropolitan Region Using a Logistic Regression Model. International Journal of Urban Sciences, Taylor& Francis Publications; DOI: 10.1080/12265934.2016.1162728. "in press"

[7] Taher Osman, Prasanna Divigalpitiya, & Takafumi Arima, 2015. Effect of governmental housing regulations on the Egyptian housing market: Focusing on Greater Cairo Metropolitan Region, Journal of Architecture and Urban Design, No. 28, July, 1–9.

[8] El-Batran, M., and Arandel C., 1998. A shelter of their own: informal settlement expansion in Greater Cairo and government responses. Environment and Urbanization, Vol. 10(1), April.

[9] JICA, 2008. The strategic urban development master plan study for sustainable development of the Greater Cairo region in the Arab Republic of Egypt. The final report summary, volume 1. Cairo, Egypt.
[10] El-Hefnawi, A. & Madbouly, M., 2001. The challenges facing peripheral lands in Giza city, Egypt, Trailog International, Journal for Planning and Building in the Third World, Issue no. 70, October.
[11] Yeh, A.G., 2002. GIS as a tool to manage urban growth in a fast growing region, Centre of Urban Planning and Environmental Management, University of Hong Kong.
[12] Clarke, K.C., & Gaydos, L.J., 1998. Loose-coupling a cellular automata model and GIS: Long-term urban growth prediction for San Francisco and Washington/Baltimore. International Journal of Geographical Information Science, 12, 699–714.
[13] Wolfram, S., 1984. Cellular automata as models of complexity. Nature 311, (October 4, 1984), 419–424; doi: 10.1038/311419a0.
[14] Clarke, K.C., Hoppen, S., & Gaydos, L., 1997. A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. Environment and Planning B: Planning and Design, 24, 247–261.
[15] Silva, E. & Clarke, K.C., 2002. Calibration of the SLEUTH urban growth model for Lisbon and Porto, Portugal, Computers, Environment and Urban Systems, vol. 26, pp. 525–552, doi: 10.1016/S0198-9715 (02)00011-X.
[16] Dietzel, C., Herold, M., Hemphill, J.J., & Clarke, K.C., 2005. Spatiotemporal dynamics in California's Central Valley: Empirical links to urban theory. Int. J. Geog. Inf. Sci. 19 (2), 175–195.
[17] Wu, X., et al., 2009. Performance evaluation of the SLEUTH model in the Shenyang metropolitan area of northeastern China. Environ. Model. Assess. 14 (2), 221–230.
[18] Heinsch, L., Lauf, S., Kleinschmit, B., 2012. Modeling urban growth and land use change with a cellular automaton in the Berlin metropolitan region. GIS-Zeitschrift für Geoinformatik 25 (2), 56–68.
[19] Ayazli, I.E., Batuk, F. & Kleinschmit, B., 2010. Simulating land use changes driven by a 3rd Bosphorus Bridge. ASPRS/CaGIS 2010 Fall Specialty Conference, November 15–19, 2010, Orlando, Florida.
[20] Antrop, M., 2004. Landscape change and the urbanization process in Europe. Landsc. Urban Plan. vol. 67 (1–4), 9–26.
[21] Geurs, K.T., van Wee, B., 2004. Accessibility evaluation of land-use and transport strategies: Review and research directions. J. Transp. Geogr. 12, 127–140.
[22] Jantz, C.A., Goetz, S.J. & Shelley, M.K., 2003. Using the SLEUTH urban growth model to simulate the impacts of future policy scenarios on urban land use in the Baltimore/Washington metropolitan area. Environment and Planning B: Planning and Design, vol. 30, pp. 251–271, doi: 10.1068/b2983.
[23] Yang, X., & Lo, C.P., 2003. Modeling urban growth and landscape changes in the Atlanta metropolitan area. International Journal of Geographical Information Science, 17, 463–488.
[24] Herold, M., Goldstein, N. C., & Clarke, K. C., 2003. The spatiotemporal form of urban growth: Measurement, analysis and modeling. Remote Sensing of Environment, 86, 286–302.
[25] Xiang W. & Clarke, K.C., 2003. The use of scenarios in land-use planning, Environment and Planning B: Planning and Design, Vol. 30, 885–909.
[26] Nassauer, J. I. & Corry, R.C., 2004. Using normative scenarios in landscape ecology, Landscape Ecology, Vol. 19, pp. 343–356.
[27] Song, Y., C. Ding & Knaap, G., 2006. Envisioning Beijing 2020 through sketches of urban scenarios, Habitat International, Vol. 30, 1018–1034.
[28] Abd-Allah, M.M. A.., 2007. Modelling urban dynamics using geographic information systems, remote sensing and urban growth models, PhD thesis, Cairo University, Faculty of Engineering, Cairo, Egypt.
[29] Yang, X., 2000. Integrating image analysis and dynamic spatial modelling with GIS in a rapidly suburbanizing environment. PhD dissertation, University of Georgia, Athens, Georgia.
[30] Kruse, F.A., 1988. Use of airborne imaging spectrometer data to map minerals associated with hydrothermally altered rocks in the northern Grapevine Mountains. Nevada Remote Sensing of the Environment, 24 (11), pp. 31–51.
[31] Leao, S., Bishop, I. & Evans, D., 2004. Simulating urban growth in a developing nation's region using a CA-based model. Journal of Urban Planning and Development 130(3), 145–158.
[32] Oguz, H, Klein, A.G & Srinivasan, R., 2007. Using the SLEUTH urban growth model to simulate the impact of future policy scenarios on urban land use in the Houston–Galveston–Brazoria CMSA. Research Journal of Social Science 2, 72–82.

[33] Bihamta, N., Soffianian, A., Fakheran, S., & Gholamalifard, M. (2014). Using the SLEUTH urban growth model to simulate future urban expansion of the Isfahan metropolitan area, Iran. Journal of the Indian Society of Remote Sensing, 43(2), 407–414.
[34] Rafiee, R., Mahiny, A.S., Khorasani, N., Darvishsefat, A.A., & Danekar, A., 2009. Simulating urban growth in Mashad City, Iran through the SLEUTH model (UGM). Cities, 26(1), 19–26.
[35] Sakieh, Y., Amiri, B. J., Danekar, A., Feghhi, J., & Dezhkam, S., 2014. Simulating urban expansion and scenario prediction using a cellular automata urban growth model, SLEUTH, through a case study of Karaj City, Iran. Housing and the Built Environment. doi: 10.1007/s10901-014-9432-3.
[36] Tan, L., Li, M. C., Liu, Y. X., Wei, H., & Hu, W. (2009). Study of urban expansion simulation on the condition of ecological environment protection: A case study in Dianchi Basin in Kunming. Urban remote sensing event Joint (pp. 1–6). Shanghai: IEEE.
[37] Akin, A., Clarke, K.C. & Berberoglu, S., 2014. The impact of historical exclusion on the calibration of the SLEUTH urban growth model. International Journal of Applied Earth Observation and Geoinformation, 27(PARTB), pp.156–168. Available at: http://dx.doi.org/10.1016/j.jag.2013.10.002.
[38] Mahiny, A. S., & Gholamalifard, M., 2007. Dynamic spatial modeling of urban growth through cellular automata in a GIS environment. International Journal of Environmental Research, 1(3), 272–279.
[39] Mahiny, A.S., & Clarke, K.C., 2013. Simulating hydrologic impacts of urban growth using SLEUTH, multi criteria evaluation and runoff modeling. Journal of Environmental Informatics, 22(1), 27–38.
[40] Dezhkam, S., Amiri, B. J., Darvishsefat, A. A., & Sakieh, Y., 2014. Simulating the urban growth dimensions and scenario prediction through sleuth model: A case study of Rasht County, Guilan, Iran. GeoJournal, 79(5), 591–604.
[41] Poelmans, L., & Van Rompaey, A., 2009. Detecting and modelling spatial patterns of urban sprawl in highly fragmented areas: A case study in the Flanders-Brussels region. Landscape and Urban Planning, 93(1), 10–19.
[42] Syphard, A.D., Clarke, K.C., & Franklin, J., 2005. Using a cellular automaton model to forecast the effects of urban growth on habitat pattern in southern California. Ecological Complexity, 2, 185–203.
[43] Gandhi, S. I., & Suresh, V. M., (2012). Prediction of urban sprawl in Hyderabad City using spatial model, remote sensing and GIS techniques geography. International Journal of Scientific Research, ISSN No 2277–8179.
[44] Dadashpoor, H. & Nateghi, M., 2015. Simulating spatial pattern of urban growth using GIS-based SLEUTH model: a case study of eastern corridor of Tehran metropolitan region, Iran. Environment, Development and Sustainability. Available at: http://link.springer.com/10.1007/s10668-015-9744-9.
[45] Jafarnezhad, J., 2014. Simulating urban growth through the SLEUTH–GA model and comparison of its results with common SLEUTH – A case study of Gorgan, Gonbadekavoos and Azadshahr Cities. In: M. Sc. Thesis. Gorgan University of Agriculture and Natural Resources.

8. Synthesis

8. Synthesis

8.1 Conclusions

The conclusions of the research findings are presented in this section as a summary of results and discussions for the specific research objectives.

8.1.1 Objective 1

The first objective was to identify the effects of changes in accumulated governmental housing policies to meet the rapid demand for the low-cost housing. The issue of low-cost housing access was visible among young families. New home-seekers of low-class incomes are challenged by two dilemmas; firstly, shortage of rent-controlled living quarters within GCMR's condominiums; secondly, they cannot pay for the inflated rates of newly established formal dwelling houses. The sustained grows in land speculation within and around urban centers created increasing prices, leaving low and middle-income urban dwellers with no affordable alternative to the informal housing market. As they are eliminated from the formal dwelling housing market, there are no alternatives for young peoples, other than houses in the informal housing sector the in the outskirt of the metropolitan areas. In spite of the urgent necessity for low-cost dwelling house supplies for people's those have restricted incomes, the general state policy targeted to establish high-class dwelling house building. We observed two main influences of housing policies, which formulate the GCMR housing market in 2000s and leads to be the informal housing sector the main provider for the low-cost housing units: (1) The Failure of governmental policies to decrease the numbers of vacant housing units in GCMR, and (2) The failure to attract residents to low-cost housing units in new urban communities (NUC) instead of informal housing areas. NUC especially could not attract residents from Cairo centers. Sub-standard services and shortage of social and educational infrastructure have also frustrated families from living in NUC.

8.1.2 Objective 2

The second objective was to develop spatial indices to quantify and analyze the spatial-temporal urban sprawl patterns in Giza governorate. In chapter 3, Remote sensing (RS) and Geographical Information Systems (GIS) techniques were used to quantify the spatial-temporal urban sprawl situation and to develop and analyze a new set of indicators that signifies its relationship. 10 urban sprawl indices were developed to analyze spatial-temporal urban sprawl patterns. The findings reveal that Buildable-arable lands in Giza have kept a rapid expansion with a huge amount of low effectiveness and dysfunctional spatial distribution. The subsequent definite sprawl attributes are determined; conspicuous fragmentation and unevenness of landscape due to ineffective implementation of land use planning; inappropriate pattern of land use growth with exemplary discontinuous development, strip development and leapfrog development; low density of land use growth, low population density and economic output in the newly developed land (NDL); and other unfavorable influences on agriculture, environment and region life. Negative impacts on agriculture lands, environment, and region life were observed from the indices. Firstly, urban sprawl has led to enormous loss of high-quality arable lands in the region`s outskirts. Secondly, the urban sprawl led to inconsiderable traffic issues. The integrated sprawl index (ISI) categorized NDL to three categories: low, moderate, and high sprawling. High sprawling scored 19.9% in the north sector, while it was 46% in the south sector, and 25.8% in the middle Sector. Moderate sprawling scored 30.5% in the north sector, 28.1% in south sector, and 24.0% in the middle Sector. Low sprawling scored 49.6% in The North, 74.5% in South, and 50.2% in middle sectors. In addition to that, serious sprawling fundamentally located in three spots particularly, in the farthest part of Northern sector around the regional transportation network, middle and southern parts of Central sector near to CBD and surround main urban centers of cities and mother villages.

8.1.3 Objective 3

The third objective was to explore the physical and socio-economic driving forces and their influences on urban sprawl. **In chapter 4,** Logistic regression model was applied to identify the physical driving forces, The findings of this paper show that the Giza governorate witnessed a significant demand for more buildable lands for urban expansion along its edges in the whole three study sectors of Giza governorate. During this period, developed land expanded at a rate 16 % higher than the growth of the population. These findings provide proof of the decreased significance of the CBD and Nile River in all study sectors as drivers of sprawl while the significance of local urban centers has increased. Moreover, we found that accessibility factors, especially the distances to existing urban areas and major roads, are important factors of urban sprawl; although the relative magnitude of the effect varied across all three study sectors. Neighborhood factors have the highest positive effect on urban expansion, indicating that urban expansion tended to take place in locations near developed areas. This means the Giza built environment will keep fast expansion in the future around the existing urban sprawl locations, which will lead to more informal areas and will continue to lead to more deterioration of the urban environment and degradation of agricultural lands.

In **chapter 5**, AHP method was applied to determine the driving forces of urban sprawl and analyzes their relative influence on urban sprawl. AHP analysis results revealed that Giza development plans had the lowest significance as a driving force in urban extension. By contrast, in all three study sectors, population increases were indicated as having high significance. Moreover, the results highlighted significant differences between the study sectors in regard to driving forces in urban sprawl. For instance, in the middle sector, economic incentives and the availability of life facilities were the most important driving forces; in the south sector, administrative functions and land demand and supply were the most significant driving forces; and in the north sector, population increases and administrative functions were the most active driving forces. The results highlighted significant differences among the study sectors in regard to internal urban sprawl drivers; these results ensure that tailored urban plans for each sector are formulated as a substitute for the current plans, which have ignored such differences and have treated the entire governorate as a single unit. This has led to a vacuum of effective plans for directing urban expansion in Giza.

8.1.4 Objective 4

The fourth objective was to assess the consequences of different policy interventions on future urban sprawl patterns and potential risks on agricultural lands. In **chapter 6**, an integrated model based on Markov chain (MC), cellular automata (CA), logistic regression (LR), called MC-CA-LR was applied to simulate three urban development scenarios namely, historical growth trend (HGT), compact growth (CG) and growth as planned officially (GPO). The analysis results showed that in the period of the past nine years, the urban sprawl primarily spreads in the whole study area. Under the HGT, and GPO scenarios, the urban sprawl will emerge the whole study urban areas while under CG scenario, the urban sprawl will discontinuously expand around with Major urban areas only, or continue to surround the Major road networks. the results show that just under the HGT scenario, the sustainable development in GCMR cannot be assured in the future, while under the CG scenarios, the Agriculture lands erosion-risk level will be much lower than that under the HGT and GPO, proving that the CG scenario was more effective in meeting the goal of environment protection and urban sustainable development.

In **chapter 7**, a SLEUTH model was applied to investigate the effects of three urban development scenarios namely, historical growth trend (HGT), compact growth (CG) and growth as planned officially (GPO), on urban sprawl focusing on the middle sector of Giza governorate. The model outputs from the HGT and GPO scenarios demonstrate that small urban clusters would expand outward and merge together to make larger urban clusters. This would change the middle sector’s spatial form significantly. The arable lands will be reduced by approximately 31 – 19% by 2035 if the existing rate and type of urban growth do not change. The results showed higher dispersed development patterns for HGT scenario than GPO scenario while the CG shows highly constrained growth, with most occurring in and around major urban centers. Due to the higher levels of protection, the growth rates for CG Scenario was reduced substantially, producing a much lower pressure on agricultural areas. On the other hand, if historical trends continue, there would be more development, but most agriculture would be lost. Subsequently, the compact growth scenario seems the most effective in limiting urban growth and preserving agriculture. The findings are representing significant implications in the flat surface agriculture environment of urban growth. First, as tiny and isolated urban patches could easily induce new development, freezing growth around these patches could prevent the inefficient urban growth. Second, to protect agriculture, setting limitations to urban development around major roads might be an applicable measure. However, there is no optimal solution to urban development and agriculture conservation is conflicting goals. If the priority is given to development, the HGT scenario is preferable as it produced the newest urban area. However, if the priority is agriculture conservation, the other two scenarios are recommendable as productive lands were largely protected.

8.2 Reflection

This section reflects on the findings and results of the study. It includes a summary of the main contributions and recommendations for further research.

First, the study extends the knowledge of the nature of Informal housing sector and related urban sprawl phenomenon. This study provides an understanding of the occurrence of this phenomenon and their relations with the official Egyptian housing policies during 70 years, with a particular focus on low-cost housing class in GCMR.As a result, this study identified the major two reasons of expanding the informal housing sector and became the main providers of the low-cost housing sector in GCMR with related economic activities which lead ultimately to high rates of urban sprawl in GCMR outskirt agricultural-lands, particularly in Giza.

Second, this study mainly extends the knowledge on the complexity of the urban sprawl phenomenon. This study provides a rich understanding of the complex mutual interaction between urban growth and their drivers, with a particular focus on the spatial-temporal process of this interaction. As a result, this study has contributed to an in-depth insight of the consequences of rapid urban sprawl phenomenon on agricultural lands, particularly in Giza governorate.

The third major contribution of this study is the development of sophisticated methods and indicators using RS and GIS techniques. This study has bridged the knowledge gap on the development of easy to use measures (indicators) to quantify and analyze the spatial-temporal relationship between urban sprawl and their drivers.

The fourth major contribution is related to the use of advances in spatial analysis and spatial statistics in conjunction with RS and GIS techniques to make an in-depth study of the complex urban sprawl process. This study extends current research using methods for exploring and analyzing urban sprawl drivers and their interaction. It provides urban planners and policy makers with a new methodological approach to understand the complex urban sprawl phenomenon in rapidly growing cities. This approach facilitates the investigation of the causes and drivers of urban sprawl; the complex interaction between the physical components of urban sprawl (spatial expansion and LUC) and related physical and socio-economic drivers.

The fifth major contribution is related to the dynamic integrated modeling approach of urban sprawl (land use change). This study introduces an integrated model based on Markov chain (MC), cellular automata (CA), logistic regression (LR), called MC-CA-LR for whole study area which included a systematic practical calibration approach (3-stage calibration approach) with a particular focus on the simultaneous interaction between land use and their physical and socio-economic drivers. Moreover, this study applied SLEUTH model to discover the urban sprawl consequences based on three development scenarios in the middle sector which witnessed the highest growth rates in Giza governorate to compare their results with MC-CA-LR model. The mode discovered the consequences of three urban development scenarios on the built environment and agricultural lands in whole Giza governorate which extends the knowledge of land-use change simulation models and facilitates the understanding of the complex spatial-temporal interaction between land-use change and related drivers.

The final contribution of this study is related to the support of planning practice in Giza. This study provides an empirical base to Giza's urban planners to understand the main features of urban sprawl and their driver's interaction, its main spatial and temporal characteristics and policy implications for urban planning and, land use planning. The calibrated model enables urban planners to take an innovative and proactive approach to evaluate the consequences of a variety of courses of action based on specific development scenarios at early planning stages. It has the ability to guide the appropriate policy interventions in place and time which provides the basis for a more informed planning process to be implemented at the local level, which current traditional planning practice and static urban models in Giza municipality cannot provide. This, in turn, helps to mitigate the negative impacts of rapid urban sprawl particularly on Agricultural-lands loss in Giza governorate.

8.3 Further research needs

Further inclusion of the socioeconomic characteristics such as income must be considered in the analysis of the interaction of urban growth drivers. This should include the effect of the spatial and temporal distribution of different population groups in terms of their income or social status on the spatial patterns of urban sprawl.

The same applies to information on land prices. Such information may improve the model since these factors contribute to the mechanisms driving the informal land market. Implicitly, this information is already incorporated in the model since the cell properties generated can be argued to implicitly represent land prices by considering some features usually determining to price. But as local land pricing only partly follows typical market mechanisms, incorporating these into the model could, to some extent, help to better explain developments which cannot be captured by the current set of variables.

Owing to the spatial extent of the metropolitan area, it seems imperative to look at driving forces of urban growth at disaggregate spatial scale including more variables such as socio-economic variables and most importantly land tenure system. This could reveal detail causal factors of urban growth pattern at the local level and could give a good explanation for potential constraint or insignificant factors for urban growth in the study area. The sprawl patterns identified from spatial indices analysis can be adopted for this purpose. However, the results of this model can be used as a base for future studies and can help planners and policy makers develop alternative urban growth scenarios.

Since the experiences made working on the case of GCMR underpinned the notion of a data-poor environment the model database has turned out to be among the most challenging issues to tackle. Besides the general issue of the absence of data, the problem of historic and recent data alike became evident. The given prevailing framing conditions found in GCMR can be assumed to be quite similar in most developing countries. Thus, the question arises how such models can be supplied regularly with recent data keeping their information base up-to-date.

Adding to the issues associated with the model's database, the extent of the study area has turned out to be problematic. This is due to the fact that for some parts of the study area urban sprawl in 2013 commenced reaching the edges of the current study extent. This impacted on the time horizon of the simulation period which has in response been confined by the authors to 2035. In order to enable for simulations beyond this time horizon, the study area would have to be extended in order to avoid distortions by cells being allocated differently due to urban growth reaching the edges of the study area. However, this would impact immediately on the model database which in consequence would also need to be extended aggravating the issue of data availability.

In this study Landsat, satellite data are used for urban change mapping, which has a 30m spatial resolution. Use of Landsat data for identification of urban sprawl areas is difficult due to its low resolution and when urban sprawl patches are small, scattered and mixed with the other urban categories. The satellite data can also be used for income level based classification of an urban area but for this we require high-resolution satellite data to differentiate the microstructure of land use for analysis along with ancillary data or field survey for verification. Landsat satellite data used in this research have certain limitation for such kind of classification. It is difficult to distinguish micro-structures, such as individual house and roads less than 30m width using Landsat satellite data. The urban mapping derived from higher-spatial-resolution imagery (e.g. IKONOS, QuickBird) have more prospects for efficient planning and management of city developments.

Thus, the authors recommend research on a comprehensive (multi-temporal) database covering the whole of GCMR. Such project could also provide valuable information for the extension of the model database. The model currently cannot consider potentially relevant information.

Moreover, the presented models will need modifications and extensions depending on the aims of such a study. With respect to scenario simulation CA models (SLEUTH and Markov chain) are rather limited to the variables directly considered by the model. Thus, it may also be disputable and subject to further research if more sophisticated means of the urban simulation may be implementable in the context of developing countries. On the one hand, these models demand far more sophisticated databases and are much more complex but they also offer the ability to further elaborate on the likely impacts of changes in behavior, policies, economic performance, etc. These issues may be of particular interest also for the aforementioned climate change debate.

In addition, the authors would like to stress the application potential of such model considering the current debate on global climate change. Urban growth models may potentially contribute significantly for instance by simulating impacts of urban sprawl and planning measures on CO2 emissions. Furthermore, the impacts of urban sprawl on natural resources like loss of CO2 sinks related to deforestation due to residential or agricultural land demand may be explored by future research. The authors are confident that such modeling exercise would open up an in-depth laboratory for further research.

Finally, more research has to be spent on the establishment and implement ability of such models into local planning processes in GCMR as well as in other Egyptian Major cities. Such models hold considerable potentials but also require a sound application and a suitable embedding. Furthermore, participatory approaches involving local stakeholders and residents into the model design, database updates, and elaboration of scenarios seem to be a promising approach largely untackled by research so far. Most of the related issues could only be named very briefly in this study and in order to take the step towards a real-world decision support system more research and practical experience are strongly required.