Modeling urban growth scenarios in Cairo Metropolitan Region 2035

Taher Osman, Prasanna Divigalpitiya and Takafumi Arima

Abstract

The goal of this research was simulating future urban growth of the Cairo region from 2015 to 2035, by making use of cellular automata methodology in the SLEUTH modelling. The input data required by the model, including Slope, Land use, Exclusion, Urban growth, Transportation and Hillshade which were derived from three Landsat satellite images from 1984, 2000, and 2013 according to supervised classification. Three scenarios were designed to simulate the spatial pattern of urban growth. The first scenario is Historical growth trends to simulate the persisted growth trends by preserving the existing conditions. The second is a compact growth scenario with robust restrictions on development in areas that are outside of designated growth centers. The third scenario is growth as planned officially that integrates stricter growth plans and stronger protections on natural resource lands at a level that could be realistically accomplished with strong political obligation. Calibration of the SLEUTH model for Cairo metropolitan area manifested a high road coefficient beside similar high spread coefficient, which implies that the predicted mode of growth in Cairo are road influenced growth, and edge growth.

Taher Osman (Corresponding author) • Prasanna Divigalpitiya • Takafumi Arima

Department of Urban Design, Planning and Disaster Management, Graduate School of Human-Environment Studies, Kyushu University, Japan
Email: taher@kyudai.jp

Prasanna Divigalpitiya
Email: prasanna@ arch.kyushu-u.ac.jp

Takafumi Arima
Email:arima@arch.kyushu-u.ac.jp

1. Introduction

Intense pressure occurred by urban sprawl actions on natural resources, particularly agriculture lands refers the significance of urban-related dilemmas in the management and development of these complex environments (Bathrellos et al. 2008). New approaches like sustainable development and smart growth need thorough analysis, grasp and modeling of urban systems in which an additional level of knowledge to confront the reasons, influences and chronology of urban sprawl techniques can be created (Asgarian et al. 2014). Furthermore, in the procedure of decision making, land managers need to test the outputs imparted by the urban evolution actions. Urban growth models fulfill this demand, and there has been a growing body of work in the field of urban growth modeling in the literature (Batty 1989). Urban sprawl is now a prevailing attributes of all countries, particularly in countries of the developing countries. Urban sprawl and land use, alteration have been the focus of regard. The wise, the promotion of urban sprawl, intensive land use, raise energy efficacy and promoting economic boom and social advance, otherwise, induces a set of influences on the socioeconomic development.

The study of urban growth and land use, alteration evinces highly significant for preparation of rational urban growth plans, and sustainable development. Spatially outright urban growth models that can affect urban development in the past and anticipate the growth scenarios in the future are necessary for assessing urban planning plans. Dynamic spatial models are helpful tools to grasp the urban sprawl actions and support urban planning and management plans. Over the past decades, a considerable deal of research potentials has been guided to evolve dynamic models in urban applications. Evolution within the computer sciences, connected with highly raised accessibility to affordable remotely sensed data, has led to the employ of these new urban growth models in both a strategy and theoretical cases. Recently, (CA) model has drawn the most research regard as they coincide with our intuitive sense that human spatial activities are not centrally arranged, but stochastic. Its robust potentials in simulating space of the spatial and temporal development of complex systems are perfectly convenient for the complex Geo-spatial and temporal attributes of system simulation.

Owing to its affinity with complex urban system, CA-based models have been vastly utilized in identifying various urban phenomena, like urban sprawl, urban form alteration, and etcetera. The SLEUTH model, a CA-based dynamic model, is situated inside the current scene of the urban modeling as a supple, strong, trusty tool which can be matched and can be competitive with the other CA models. It developed the CA's potentials to identify real land use, alteration and have drawn considerable regard in the research community. This research incorporated geographical information systems (GIS), satellite remote sensing (RS) and SLEUTH model to detect urban growth techniques and test the alternative planning scenarios in Cairo, Egypt. By adjusting the model parameters and applying, to the growth of the Cairo region of the simulation, the paper seeks at reconstructing and predict the trends of urban sprawl in Cairo, analyzing the reasons and influences for associated studies.

2. Data and Method

2.1 Study Area and Data

Cairo region is situated at latitude 30_ 060 N and longitude 31 280 E at an altitude of 74.5 m as l. The region is situated 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 1. The region is described by El Moqattam hills to the south east and desert areas in east side 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 bare desert lands of the east. Cairo has a wide diversity of internal urban division characteristics such 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: Haigh class residential areas with 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 submitted in figure 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 square km (27900 Hectare) and implicates a diverse types of land uses and urban densities.

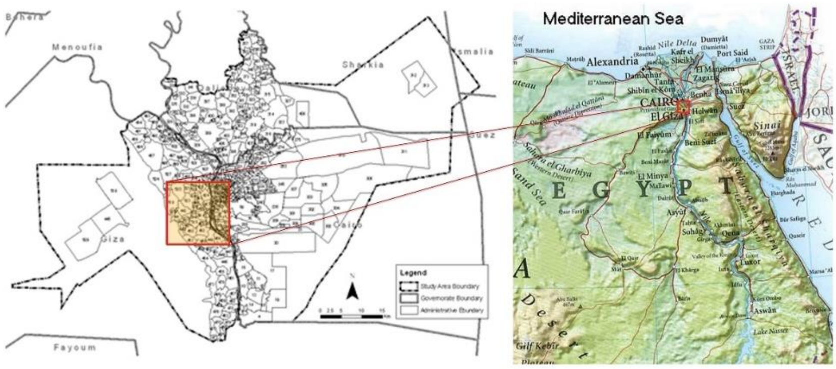

Fig. 1 The study area

The primary data in this paper are three Landsat TM images in 1984, 2000, and 2013. Table 1 lists the SLEUTH model data requirement and generation methods. To accomplish the input prerequisites of the model, supervised image classification was achieved to derive land use maps, road networks 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 to three region road maps of 1984, 2000, and 2013. For the calibration stage, the excluded layer comprised of water, which was 100% excluded from development, in addition to historical sites, protected areas and local parks. All the data layers were referenced to the same Universal Transverse Mercator (UTM) 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 checked for overlay accuracy. Because SLEUTH needs a binary representation, these continuous data were converted into 8-bit grayscale image of the GIF format.

Table 1. Data requirements for SLEUTH Modelling

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

2.2 Modeling approach

The SLEUTH model (slope, land use, exclusion, urban growth, transportation and Hillshade), is a development of Urban Growth Model, established for the first time in 1998 by Keith Clarke. So it is built in two different modules, which can be operated autonomously: Urban Growth Model (UGM), which simulates the urban growth, and a Land Cover Model (DLM), that lets monitoring the alterations in land uses. In its major module, SLEUTH is a probabilistic model with Boolean logic. This approach explains the employ of brute force calibration according to the study of parameters in decisive ranges which are gradually decreased. This model is valued for the parameters potentials in adjusting and explaining different phenomena of different areas. Consequently, there isn't any limit in dimension of the research area: there are case studies about an entire region and other application about a single city. SLEUTH anticipates urban growth, according to a diversity of growth rules, the type of urban cells, the interaction of urban cells and their environment (Clarke and Gaydos, 1998). It is carried out in two general stages: a calibration stage, where the model re-use historical development trends; and a prediction stage, where historical trends are directed into the future. This lets the model to equivalent known historical circumstances and help in grasp the different values in a probabilistic way (Claire et al., 2003).

The time unit of the urban growth simulation is the growth cycle, and it corresponds to one year. Urban growth dynamics in UGM module (which supplies probabilistic information) are modeled using four sequential rules table 3: spontaneous new growth; organic new spreading centers; diffuse edge growth; and road influenced growth. All the cells which compose the entire automata are upgraded on the entire grid after each rule application. These are utilized respectively, during each growth cycle and controlled through the interactions of five growth parameters: dispersion; breed; spread; road gravity and slope. The five parameters affect the way how the transition rules, which depict the growth and alteration of the region, can be utilized. The first four parameters submitted above table 1 depict the growth pressure in the urban system. Resistance to growth is integrated through the slope resistance parameters, which identifies the impact of steep slopes on restricting development, and through a user-defined excluded layer, which explains areas that are wholly (e.g. Water or parks) or partly (e.g. Restrictive zoning) eliminated from development.

Table 2. Controlling Coefficients Description

Controlling Coefficients	Summary Description
Dispersion coefficient (DI)	It manages the number of time that a cell is randomly chosen to be urbanized during the application of spontaneous growth law
Breed coefficient (BR)	It regulates the probability of an urbanized cell, in the spontaneous growth stage, to be a new urban core which has the probability to develop (new spreading center). Furthermore BR is utilized road-influenced growth stage, regulating the spread along a road
Spread coefficient (SP)	It explains the probability that a cell, which is part of a spreading center (a cluster with at least two urbanized cells, in a 5x5 neighborhood), derives another urbanized cell in its neighborhood
Road gravity coefficient (RG)	It explains the maximum affect distance for each road on urban sprawl probability. It relies also from the input map dimension
Slope resistance coefficient (SR)	It regulates the weight of the probability that a location may be built up.

Table 3. Relationship between growth types and growth coefficients

Growth Cycle	Growth type	Controlling coefficients	Summary description
1	Spontaneous	Dispersion Slope resistance	Randomly choose a potential new growth cells
2	New spreading Center	Breed Slope resistance	Growing urban centers from spontaneous new growth
3	Edge	Spread Slope resistance	Old or new urban centers grow outward
4	Road influenced	Road-gravity Dispersion Breed Slope resistance	Newly urbanized cell spawns growth along transportation network
Throughout	Slope Resistance	Slope Resistance	Impact of slope on decreasing probability of development
Throughout	Excluded layer	User-defined	User specified areas resistant to or eliminated from development

2.3 Calibration

It 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 are then averaged over the group of MC reiterations and matched 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 comparing values specified the range of scores utilized in the subsequent stage of calibration. Descriptive statistics were computed for the group of top values to help in the determination of a 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 urban year 1984 is utilized as the seed, and related urban layers, or control years 2000, 2013, were utilized to compute several statistically best-fit values; the model was then 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 anticipate future types of urban sprawl, permitting the model to equivalent known historical circumstances, as long as help in grasp the significance and density of the different values probabilistically. 100 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 mapped 2013 growth.

2.4 Prediction

Urban growth prediction is the most significant application of the SLEUTH model. Based on the needs, different scenarios can be prepared to predict the future growth of the region. This paper in the model prediction to the latest dilemma of urban sprawl for the base map layers, using the final correct scores for correction, through the 100 MC examines the probability of future urban plans, inclusive the urbanization probability of more than 90% of the cells as predict urban land use. To derive various scenarios of urban sprawl in layers, over the prediction can be grouped various basic circumstances. Three future growth scenarios were simulated: Historical growth trends, Compact growth and Growth as planned officially. 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 future determined developments in the historical growth trends scenario.

3. Result

3.1. Calibration

After precisely checking various parameter groups according to various fit statistics, we establish the parameters according to the compare metric were fit to identify the value of growth that occurred in the system, and were also fit to simulate urban form effective, as proved by the high value (all scores above 0.53) for the Lee-Sallee metric. Consequently, we utilized the compare 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 4. These parameter scores specified the growth trends that were utilized to predict future development types.

After the calibration, urban growth and renewal actions can be simulated. The simulation is helpful to understand the self-organizing urban characterize and identify the techniques and reasons of urban sprawl more exceedingly. Using the final parameter scores above, the urban growth simulation of Cairo from 1984 to 2013 is rebuilt with a statistical match degree figure 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 sprawl at most from the centers to the fringes, as long as along the transportation networks. The low dispersion value signifies the phenomenon of spontaneous forming urban spots in low-density areas is not clear.

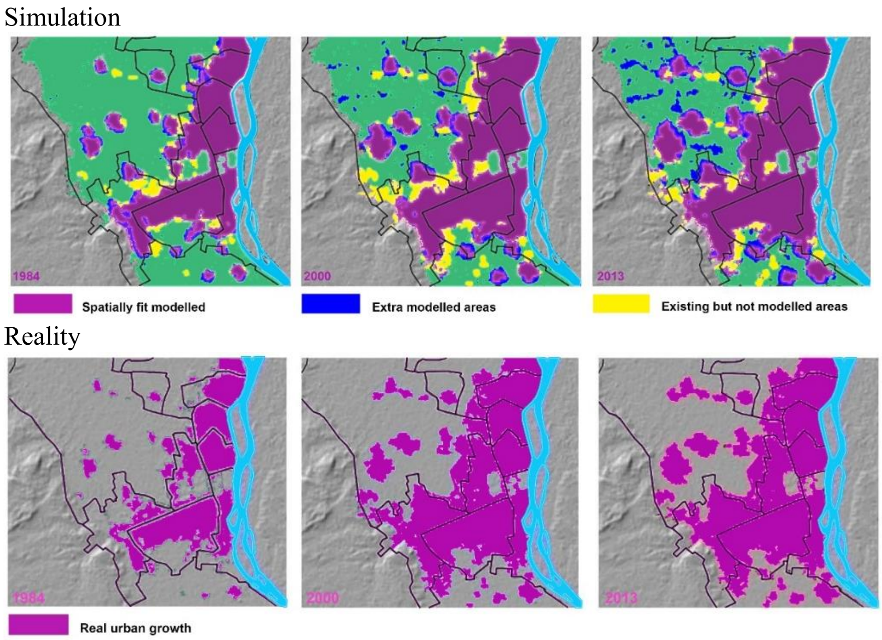

Fig. 2 Urban growth simulation versus reality in Cairo from 1984 to 2013

Table 4. SLEUTH indices for evaluating the accuracy of the simulated output of the model during calibration phases

Index	Definition
Compare	Comparison of modeled final urban growth to real final urban growth
r2 Population	Least square regression scores of modeled urban sprawl compared with real urban sprawl for control years.
Edge r2	Least square regression scores of modeled urban edge count compared with the real urban edge count for control years.
R2 cluster	Least square regression scores of modeled urban clustering compared with known urban clustering for control years.
Leesalee	A shape index, a criterion of spatial fit between the modeled growth and the known urban growth for control years.
Average slope r2	Least square regression of average slope of known urban cells for control years.
% Urban	The percent of available pixels urbanized during simulation in comparison with the real urbanized pixels for each control year.
X_r2	Center of gravity [x]: Least square regression of average x values for modeled urbanized cells compared with average x values of known urban cells to control years.
Y_r2	Center of gravity [y]: Least square regression of average y values for modeled urbanized cells compared with average y values of known urban cells to control years.
Radius	The average radius of the circle that encloses the simulated urban pixels in comparison with the real urban pixels for each control year.

Table 5. Results of 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

3.2 Prediction

Besides simulating reconstruction of urban growth, SLEUTH model can also spatially identify the urban growth types in the near future under the various urban land use planning plans. This implies that some urban land use planning plans can be tested and identified to help us to further grasp the urban growth in Cairo. Three future growth scenarios were simulated: Historical growth trends, compact growth, and Growth as planned officially, 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 future determined developments in the Historical growth trends scenario.

3.2.1 Historical growth trends Scenario

The first scenario supposes that the historical growth trends would keep on when developmental circumstances do not change. Consequently, this scenario may be termed as “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 to the present simulation. The only distinction is that the 2013 urban growth data is utilized.

This scenario supposes the permanence of urban growth as the factors for the growth sustain unaltered. Consequently, it supplies a criterion for comparison with alternative growth plans. The study area simulated urban area for 2035 would be about 108.8545 Sq. Km. The net growth in urban land between 2015 and 2035 would be about 20.458 Sq. Km, identifying a raise of 23.14% in comparison with the basic area in 2015. As an output of such a growth, 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 outward fringes and join together to form much larger clusters, thus the reason of decreasing areas of agricultural lands in Cairo region. The clear alteration as predicted in the future 20 years can be identified very well from the model's visual outputs for a single year. By assessing these graphical results precisely, it is found that by approximately the year 2035, villages like Kirdasah, and Nahya would be merged together and this unified area will form a basin of agricultural land together with the major urban core of Cairo region. The output will be a huge urban that encircle agricultural lands that will soon be vanished by the future urban growth. The graphic images also identify that the agricultural lands encircled by the ring road will be totally urbanized by the impact of organic growth and road influenced growth.

3.2.2 Compact growth Scenario

This scenario supposes slowing down the urban growth rates and changing the spatial type 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 4. The projected future urban growth prediction for the other two scenarios shows that 68.3 % of the urban growth are occurring by the organic growth, and road influenced pattern is 28.4%. Whether spontaneous, and diffusive contributed to 3.3 % of the growth. The compact scenario supposes to prevent the organic, and the road influenced growth, but support the other two types of growth. Consequently, the growth of existing urban cells to their surroundings, beside the road-influenced growth should be reduced. Otherwise development of urban settlements in undeveloped areas (spontaneous growth and diffusive growth) should be raised. Based on that, more formal residential growth should be supported in the outlook simulations, and more control over unplanned growth should be conducted. To fulfill this concept in the simulation, some parameters are changed. The starting value of spread coefficient was decreased by 35% to 26, in addition to the road influence coefficient was decreased by 15% to 33 given that the road-influenced growth accounts for a very tiny share of total growth in the past two scenarios. The diffusive and breed coefficients were raised to 40 (about 72% - 78% respectively).

In the hope of encouraging more development within the new boundary of the existing villages surrounding the Giza area, the exclusion probability was set to 30% (70% urban sprawl probability). The exclusion probability was set to 55% (45% urban sprawl probability) within the boundary of the on the ring road to fulfill more Constraints on the urban development on the remained agricultural lands inside Cairo region borders. Otherwise the exclusion probability was raised to 80% (20% urban sprawl probability) in the surrounding area of Cairo region, (other than the new village's boundary and the area bounded by the ring road), to strictly prevent the growth over agricultural lands. Based on this scenario, the predicted urban land for 2035 would be about 96.55 Sq. Km. The net rise in urban land from 2015 to 2035 would be 8.154 Sq. Km, identifying a raise of 9.22 % in comparison with the basic area in 2015. By 2035, urban land would be about 12.58 % of the total agricultural land in the study area by 2035. The number of urban clusters would be 186 in comparison with215 in 2015.

3.2.3 Growth as planned officially

The third scenario considers future road development and environmental protection while other circumstances utilized in the first scenario are still valid. This submits 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 submitted by the GOPP comprises some new and upgraded roads inclusive the Northern arc that is equivalent to the current major road which starting from the ring road till the 6th October City in Al-Giza governorate. A new roads layer was submitted, with this upgraded information, for the year 2015. Otherwise, environmental protection is another significant regard for outlook urban development planning in the Cairo area. Water conservation is a crucial dilemma to confirm clean water supply throughout the region. Consequently, the protection of canals found in this area, is a key step towards this target.

To fulfill this concept in the urban modelling, some buffered zones have been created along main canals in the study area. These buffered zones cover areas of 75 m -150 m wide from the Centers of these canals. Various probabilities of exclusively for urban development are assigned for these buffered zones. The buffer zone within 75m is assigned a value of 100, meaning that this area is not permitted at all for urban development; the buffer zone between 75 m 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 outlook urban simulation under this scenario. Beside the circumstances utilized for 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 would be about 100.92 Sq. Km. The net rise in urban land from 2015 to 2035 would be about 12.532 Sq. Km, identifying a raise of 14.17 % in comparison with the basic area in 2015. By 2035, 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.

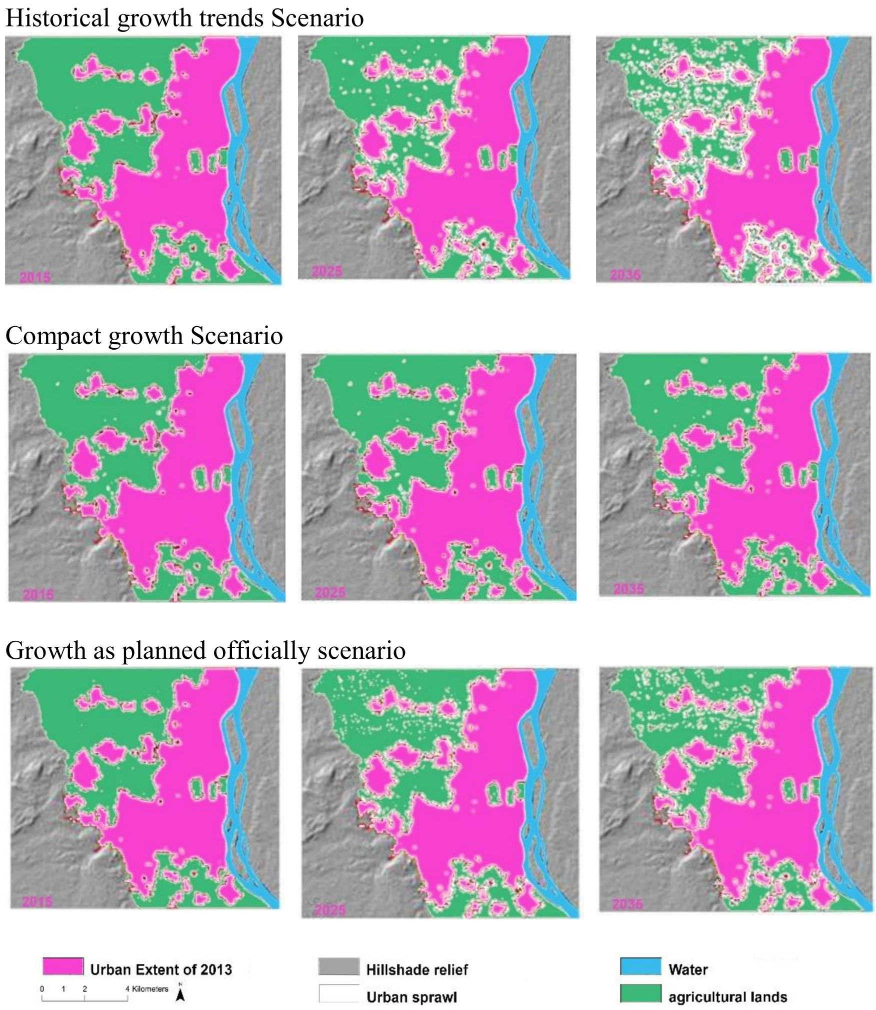

Fig. 3 Urban growth scenarios in Cairo

4. Conclusion

Based on the simulation of urban growth in Cairo from 1984 to 2013 and the prediction of the urban various growth scenarios in 2035, there is a considerable dilemma of the continuous urban sprawl with limited urban spaces, and arable lands in Giza area and the large scale of the metropolitan region. More than four decades after the open door strategy, Cairo has always taken a traditional housing, service, and industrial pattern of urban sprawl, urban edge growing from the existing districts outward to agricultural fringes. The probability of the running urban growth in the urban–rural fringe to form one edge growth and road influenced patterns are very high. Particularly the construction of the ring road in 1984 played an important driving force to support these patterns. 80's after the establishment of market economy system, converting the growth mode of economy, improving the service and industrial infrastructure, mega private housing projects, and developing of the region's infrastructure play as a crucial driving force in the Cairo's urban sprawl process. Despite the robust attractiveness of the central area is the major factor for sprawl of the urban fringes, transportation network supported this action. The effective Informal transport system composed with a ring road creates an integration process among center districts and outlying districts as one unified district, which extremely influenced the urban sprawl process. But its probability had not yet been imported into full play. In addition, as an output of Cairo's unique case in Egypt at least, its actions of urban sprawl is also influenced by a number of unanticipated driving forces. And these are some other random forces influencing the sprawl actions, which should be taken into account in the research of urban sprawl, particularly in the simulation.

As an urban dynamic simulation model, SLEUTH model can be utilized to simulate the urban growth and land-use alteration, detecting the structural characteristics and the law of urban growth. It can be utilized as a land-use planning and regional planning tool, supplying visualization actions of the outlook urban growth and land-use alteration. In this research, coupling with GIS and RS, SLEUTH model simulated Cairo urban growth from 1984 to 2013, accomplished a comparatively high degree of accuracy according to the predicted future growth results. The model predicted alterations in land-use types with a clear spatial location and quantity relationship. It can play a considerable tool in determining the scope and pace tendencies of future urban growth. However, there is still something need to develop. Simulation in the future should give more attention to the influence of socioeconomic forces, because the urban growth made not just from their own land-use units' relations, but from more subject to social, economic, cultural and many other impacts, which has imparted the simulation some challenges. Outputs manifested, that the calibrated model's predictions of spatial types from 1984 to 2013 were almost fit to coincide the growth types and effectively simulate the historic trends of growth, despite some of Cairo region fringe areas witnessed land conversion rates higher than the model could identify. Future urban growth maps, predicted out to 2035 under various land protection scenarios, were helpful for identifying potential growth, as long as for identifying the influences on arable lands.

These outputs from the first and third scenarios Simulations refer that smaller urban clusters would grow outward and join together to form much larger clusters. This would change the region's spatial form significantly, particularly if the Ring Road has been surrounded by urban areas, and not the reverse. The arable lands in our research area will reduce by approximately 31 – 19% by the year 2035 if the existing rate and type of urban growth do not change. These outputs should be helpful both to those who identify urban dynamics and those who need to supply services to people living in such swiftly alteration environment in addition to manage natural resources.

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