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# Urban land expansion model based on SLEUTH, a case study in Dongguan city, China

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**Urban land expansion model based on SLEUTH,**  
**a case study in Dongguan city, China**

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Master degree thesis in Geomatics

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## **Abstract**

The famous “World Factory” Dongguan, which is located in south of China, has been experiencing rapidly bottom-up urbanization since 1990s. For environment and sustainable development, monitoring urbanization is very important. A self-modified cellular automaton model was coupled with multi-source GIS (Geographic Information Systems) and RS (Remote Sensing) data to simulate urban growth trajectory of Dongguan city from 1997 to 2009. The accuracy of localized parameters was evaluated to illuminate the growth pattern of Dongguan. Two different scenarios were set to predict the urban development from 2022 to 2030, which shows SLEUTH is able to offer reasonable outcomes to government policy makers in terms of urban plan. Finally, the dynamic mechanism of urban growth combined with local characteristics was discussed. Some suggestions were also proposed for future urban planning and policy making in this study.

## **Keywords:**

Geography; Physical Geography; SLEUTH model; Urban growth; Dongguan; Urban planning; GIS;

# Table of Contents

Abstract.....	iii
Table of Contents.....	iv
1. Introduction.....	1
1.1 Background.....	1
1.1.1 Urban morphological and structural model.....	2
1.1.2 The application of CA in urban dynamic simulation.....	4
1.1.3 Urban planning scheme based on CA.....	5
1.1.4 Application of SLEUTH in urban growth simulation.....	6
1.2 Aim and objectives.....	7
2. Material and methodology.....	8
2.1 Input data.....	8
2.1.1 Slope layer.....	9
2.1.2 Land use layer.....	10
2.1.3 Excluded layer.....	10
2.1.4 Urban layer.....	10
2.1.5 Transportation layer.....	11
2.1.6 Hill shade.....	11
2.2 Parameters.....	11
2.3 Calibration.....	12
2.4 Urban CA growth rules.....	13
2.4.1 Spontaneous growth.....	13
2.4.2 New Spreading Center Growth.....	13
2.4.3 Edge Growth.....	14
2.4.4 Road influenced growth.....	14
2.4.5 Self-modification.....	14
2.5 Study area and data.....	15
3. Results and discussion.....	17
3.1 Historical urban growth simulation.....	17
3.2 Future Urban growth prediction under different scenarios.....	20
3.2.1 Urban growth prediction in historical scenario.....	21
3.2.2 Urban growth comparison with different parameter sets.....	23
4. Conclusion.....	25
Acknowledgements.....	27
References.....	28



# **1. Introduction**

As a combined result of human behavior, socio-economic and natural effects on different temporal and spatial scale, the mechanism and process of land use and land cover change are complicated. Land, as the resources and environment carriers, is the basis of sustainable development for environment, economy, and our society. The limited amount of national land resources and the increase of land demand in China has lead to a special conflict on sustainable land use. Monitoring the spatial-temporal patterns of urban sprawl and their impact on the environment are critically important for urban planning and sustainable development, especially in developing Chinese cities such as Dongguan (Batty M. et al., 1989).

## **1.1 Background**

Since urban models often require large amount of data and scientific computation, there are limited researches on urban models until the first computer was built in 1946. From then on, the development of urban models and applications was quite rapid and it can be divided into four periods as shown in Table 1 (Zhou C. et al., 1999). The theories reviewed below are from “Urbanization and the urban geography System” (Chen SP., 1999).

**Table 1** four periods of urban models development

Period	Sub Period	Description
<i>Urban morphological and structural model</i>	<i>Traditional static urban model</i>	<i>Focus on different land-use types/urban space structure and morphology</i>
	<i>Dynamic urban model</i>	<i>use a larger unit; involving quantities of parameters</i>
<i>The application of CA in urban dynamic simulation</i>	<i>Pure theoretical urban evolution researches based on CA</i>	<i>discrete dynamical models based on CA project urban future through simulating the past</i>
	<i>Real urban expansion simulation based on CA</i>	---
<i>Urban planning scheme based on CA</i>	---	<i>the transformation rules of CA are determined by urban planning goals</i>
<i>Application of SLEUTH in urban growth simulation</i>	---	<i>a CA-based model for simulating urban growth in order to improve in understanding of how surrounding land use change</i>

### ***1.1.1 Urban morphological and structural model***

During this period, researchers mainly concentrated on the spatial distribution of different land-use types and urban space structural and morphological representation (Dietzel C. et al., 2005). The work of Burgess published in 1925 shows us “the Concentric Urban Land Use Patterns” (EW. Burgess, 1925); German urban geographer Christaller and economist Losch proposed the remarkable “Central Place Theory” in 1930 and 1940 respectively; 1931, Reilly accepted the Law of Universal Gravitation in the Newtonian Mechanics to propose the “Retail Gravitation Law ”; two years later, Professor Colby from the University of Chicago became well known by putting forward the “Centripetal and Centrifugal Force Theory” to display urban land use change and geographical differentiation.



### ***1.1.1.1 Traditional static urban model***

In the late twentieth century, static urban models have emerged in large numbers (Couclelis H., 1985). Consisting of Spatial Diffusion Model, Distance Attenuation Law etc., Spatial Interaction Model is the most striking one, which has been widely spread afterwards.

However, the limitations of these traditional geographical models in the simulation of urban systems cannot be ignored (Li X. & Yeh A.G., 2000). Under ordinary circumstances they are static or linear analyticity models, so it is hard to reflect the dynamic land-use changes or the complexity of surface features. In addition, since traditional models usually use a larger unit (an administrative region, etc.) with insufficient detailed spatial information as the research object, that data with high resolution cannot be applied for setting up models (Couclelis H. et al., 1989). As a result of this, the city's micro-structural features and individual behavior cannot be reflected neither. Meanwhile, the traditional static models involving quantities of parameters are often difficult to generate.

### ***1.1.1.2 Dynamic urban model***

From late 1960s, there are two representatives of dynamic urban model simulation: one is the kinetic model derived from differential equations while the alternative is a discrete kinetic model which comes from cellular automata, whose abbreviation is CA (Makse H. et al., 1995). The former has been in the mainstream position for many years and until now a variety of city models based on differential equations are still the dominant trend.

Wilson (Wilson A.G., 1970) illustrated the first urban dynamic model of a set of nonlinear differential equations in 1970. The Theory of Predator-Prey showing a dynamic relationship in ecology was associated with urban dynamic analysis by Dendrinos and Mulaly (Dendrinos D.S. & Mullally H., 1985). Haag and Weidlich (Haag G. & Weidlich W., 1984) imported "the Master Equation Method" to simulate the urban dynamic behavior and constructed a dynamic structure of regional migration. With the assistance of "Dissipation and Self-organization Theory", Peter Allen developed a new urban dynamic model based on a set of nonlinear differential equations (Buchendorfer, 1997).

All of the models introduced above, both dynamic and quasi-dynamic, are derived from differential equations and emphasize the interaction and feedback among the system variables. To some extent, they can describe certain characteristics of urban

development dynamically (Batty M. et al., 1995). The variables are social and economic indicators such as population and salaries. The change of urban land-use is influenced by many factors such as the growth of population and urban sprawl speed. The spatial scale of the model is mostly based on macroscopical indexes like urban residential areas, work areas, commercial areas etc., which are difficult to present the micro-structural features (Couclelis H. et al., 1988). It can be inferred that these so-called dynamic models are seldom good at exhibiting the growing trajectory of the city (Batty M. & Xie Y., 1994).

### ***1.1.2 The application of CA in urban dynamic simulation***

In contrast, discrete dynamical models built on micro individual behaviors such as cellular automata, DLA model, Percolation model and Multi-agent model introduced a brand new idea to the world (White R. & Engelen G. et al., 1997). Batty et al. (1994) pointed out that top-down urban macro-model had been gradually replaced by those models that can simulate self-organized macroscopic behavior of a city by the local individual mutual interaction in 1995. A cellular automaton (pl. cellular automata, abbrev. CA) was first proposed by Stanislaw M. Ulam (1909-1984) and John von Neumann (1903-1957) in the 1950s. CA is a discrete dynamical system both in space and time scales. A large number of cells are distributed in a regular grid or lattice of any finite dimensions demonstrating a finite number of states (Batty M. et al., 1994). Other than general dynamical systems, CA is not defined by physical equations or functions but a combination of rules, and each rule consists of several models. The state of each cell depends on both transitional rules and its neighbors. Typically, the rule of updating for each cell is the same and will never change over time, and is applied to the whole grid simultaneously (Deal Brain & Zhanli Sun, 2005). In other words, CA is a methodological framework or an umbrella term for some certain models.

CA, as a “bottom-up” approach to simulate the spatial and temporal dynamics of urban growth, has been widespread in last decades (Chapin F.S. & Weiss S.E., 1968). With the various representations of CA-related cases, urban dynamic models have been improved and widely applied on different urban context and landscape patterns in the past few decades. This versatility is attributed to the diverse fields of urban sprawl analysis (White R. et al., 1997). According to the application purpose and model functions, the state of art of urban CA models is reviewed specifically in the following three fields.

### ***1.1.2.1 Pure theoretical urban evolution researches based on CA***

The CA model assumes that urban development is not restricted by any parameters and the space is homogeneous and constant (Tobler, 1979). The simulation of the urban expansion process is carried out in order to discuss the general law of urban growth. For example, by integrating land use model, traffic model, CA model and multi-agent model, Torrens (Torrens, 2003; 2006) create the SprawlSim Model, which stands for an important breakthrough of virtual city analysis.

### ***1.1.2.2 Real urban expansion simulation based on CA***

The purpose of most prevalent CA simulations is to explore the urban development under real constraints of the actual geographical environment. The overall objective is to project urban future through simulating the past. The works of Clarke (Clarke, 1998) together with UrbanSim model (Waddeli E., 2002) are two major representatives.

### ***1.1.3 Urban planning scheme based on CA***

The approach was first introduced to urban plan during the 1980s and has been used for many years. It will be a considerable potential division of CA (Lambin E.F. et al., 2001). Very different from other fields, the transformation rules of CA are determined by urban planning goals and guidelines rather than merely empirical data (Dietzel C.K. et al., 2004). For different developing objectives, urban planners have a variety of possible options to meet their specific requirements. Such kind of models can be part of a Planning Support System to provide solutions based on different “what-if” situations. Lessons learned from previous problems can help to reduce the possibility of similar issues occurring again in the future. Ward made a constraint CA model for the “Gold Coast” region rapid urbanization on the east coast of Australia (Ward D.P. et al., 2000); Deal designed the LEAM model used for regional planning, land use planning, watershed planning, historical and cultural heritage planning, military planning etc. in 2005 (Deal, et al., 2005).

#### ***1.1.4 Application of SLEUTH in urban growth simulation***

SLEUTH urban land use model, which is named after the six input layers Slope, Land use, Excluded, Urban, Transportation and Hillshade layers, is a CA-based model for simulating urban growth in order to improve in understanding of how surrounding land use changes due to urban expansion (Clarke K.C., 1997). It applies self-modifying CA which features the ability to modify parameter settings when the system expands exceeding a critical high or decreases under a critical low value (Hagerstrand T., 1965). The main assumption of the model is if the historical growth trajectory is persistent, the future phenomenon can be simulated by the real evolutionary trend in the past.

There have been numerous applications and ideas generated from SLEUTH in recent decades from a local to regional scale in both North America and Europe. A majority of the applications are focusing on urban growth forecasting and integrating social or physical models with planning effort (Jantz C.A. et al., 2003). In addition to modeling urban morphology in the future, trajectories of the spatial growth together with statistics are generated by coupling the historical urban extent with transportation and topographic data. SLEUTH is characterized as an approach to exploring theoretical investigation of urban processes.

Results from previous applications infer that the calibration of SLEUTH is confronted with multifaceted complexities (Clarke K.C., 1996). As early models merely concentrated on modeling of urban growth, Silva and Clarke (Silva et al., 2002) turned to develop the refined calibration of SLEUTH to Lisbon and Porto in Portugal in 2002. Studies from North American to European cities have proved that SLEUTH is a universally portable model with general applicability and the model can become more sensitive to local conditions by improving the spatial resolution. It also provided a more robust basis for other researches (Jantz et al., 2003) through a better understanding of the calibration process.

Moreover, a novel approach to simulating urbanization by coupling SLEUTH outputs with other spatiotemporal models, such as physically-based modeling efforts, has been put forward recently. Incorporating SLEUTH with the Western Futures Model, Claggett (Peter R. Claggett et al., 2004) divided the urban growth into different classes of “development pressure” based on forecasted population growth. These researches demonstrated the potential possibility of SLEUTH to be coupled with a wide array of models ranging from anthropology to environmental assessment and beyond.

As the input data of SLEUTH can be described as data layers of ArcGIS, government-induced policy and urban developing plans can be incorporated by means of adding new layers, such as a transportation layer. It can be considered as a basis of

combining scenario planning with SLEUTH which has profound impact upon urban sprawl prediction. The application of SLEUTH by Santa Barbara reported in 2003 is tailored to the specifics (Herold M. et al., 2003). For further investigation, the relation between parameters, model behavior, and scenario generation will be taken into account (Dietzel C.K. et al., 2004b).

## **1.2 Aim and objectives**

There are quite a few studies about urban land expansion based on SLEUTH model. A number of researches have been conducted from America to Europe, and some big cities in China (G. Chaudhuri & Keith C. Clarke, 2013). However, currently there is no specific study of urban growth simulation focus on the whole Dongguan City, which is located in Southern China. Thus the simulation of urban expansion at Dongguan is fairly meaningful, since it is a typical polycentric city in southern China.

Based on SLEUTH urban growth model(Batty M. et al., 1994), a simulation of Dongguan urban development from 1997 to 2009 is illustrated under the support of large spatial databases and remote sensing satellite images in a variety of resolution, the model performs well in human-induced land use change simulation both in the macro-and meso-scale from long term perspective forecasting. By analyzing the optimal parameters, the historical trend and characteristics of urban growth in Dongguan are captured, and then different scenarios are constructed to simulate the future expansion. It will provide necessary references for the researchers and government in urban planning.

The goal of this study is building up a set of spatial-temporal land resource allocation rules and developing an urban land expansion model based on CA which performs fairly well on dynamic features. The objectives of this study are:

- 1) Building a SLEUTH land use model to simulate urban growth trajectory of Dongguan city from 1997 to 2009.
- 2) Calibrating the accuracy of localized parameters to illuminate the growth pattern of Dongguan.
- 3) Based on the hypothesis that the urbanization process is as fast as before, a historical scenario from 2010 to 2050 is built up to choose the suitable study periods.
- 4) In order to prove SLEUTH is able to offer reasonable outcomes for urban plan, setting two different scenarios to predict the urban development from 2018to 2030.
- 5) Proposing some suggestions for future urban planning and policy making by combining the dynamic mechanism of urban growth with local characteristics.

## 2. Material and methodology

Here follows the general description of the input data and parameters, the deducing process and exact values are specified in the next chapter.

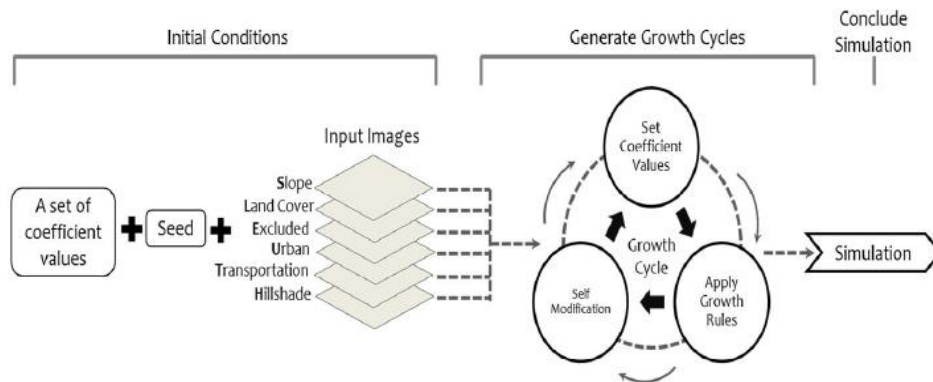
### 2.1 Input data

**Table2** The six initial input layers

Input layer	Format	Number
<i>Slope layer</i>	<i>Raster</i>	<i>One(in percent)</i>
<i>Land use layer</i>	<i>Raster</i>	<i>One</i>
<i>Excluded layer</i>	<i>Raster</i>	<i>One</i>
<i>Urban layer</i>	<i>Raster</i>	<i>At least of four different time</i>
<i>Transportation layer</i>	<i>Raster</i>	<i>At least two distinct layers</i>
<i>Hill shade</i>	<i>Raster</i>	<i>One</i>

As shown in table 2, the six initial input data layers in raster format are Slope layer, Land use layer, Excluded layer, Urban layer, Transportation layer and Hill shade layer (<http://www.ncgia.ucsb.edu/projects/gig/>). The model requires at least four Urban layers of different time, two distinct Transportation layers, as well as a Slope layer, a Hill shade layer and an Excluded layer representing area can never urbanized. All the input layers should be converted to gif format in the same urban extent, resolution and geographic coordinates unanimously.

SLEUTH is a simulating model of urban growth and its surrounding land use changes. A set of initial conditions and a growth cycle are developed for the simulation. The initial conditions are defined as: a) urban sprawl seed points; b) factors control the behavior of the system; c) input layers that the model required. A growth cycle being the elementary unit of SLEUTH model is generated when these conditions are determined (Dietzel C.K. et al., 2005). Firstly, five factors should be initialized to a unique value, then the growth rules are applied separately, evaluation of the expanding rate is following by assembling self-modification, which will adjust the coefficient values slightly to satisfy the prosperity (Boom) or depression (Bust) state corresponding to the acceleration or deceleration of growth during the urban development process, finally the results are feedback to the model for another new growth simulation (G. Chaudhuri & Keith C. Clarke, 2013)



**Figure 1 Structure of the SLEUTH model** (G. Chaudhuri & Keith C. Clarke, 2013)

There are three modes in the model: test, calibration and prediction modes. As the first step, test focus on the verification of the data sets and their initial reaction to the input data, including assuring that they conform to data input specifications (Torrens E.M. et al., 2006)..

Calibrate mode is the most complex and time-consuming section for the urban sprawl simulation. Firstly, the range and step size of parameters are set by users, then Monte Carlo iterations based on all possible parameter permutations are executed respectively to simulate each parameter to an exact value by comparing with historical land use images. Statistical data generated from such simulation loops can assess the fitness of all simulation results with real data. Ultimately, a parameter combination deemed to be the best fit parameter set will be accepted by Predict module for land use forecasting. When the calibration mode is complete, the results are used for forecasting studies, and no validation is possible without repeating the calibration.

### 2.1.1 *Slope layer*

Generally represented by slope, topography is one of the essential elements in urban development. Regions that are flat and broad are more suitable for the urban sprawl apparently (Gillissa et al., 2003). In this research, slope layer is generated from a digital elevation model (DEM) in percentage, and reclassified to integer value ranging from 0 to 100, for example, when the slope is 10%, after reclassification it will be 45. The construction cost ascends as the terrain slope is increasing. As a result, there is a “critical slope” imposing restriction on urban expansion when the incline of the topography is exceeding the superior limit. The critical gradient for urban development differs from countries, regions, and cities in China. It is generally defined as 20% for plains while mountainous or hilly areas are set to be 25%. Topography will not change dramatically in short term, so the slope layer will remain the same during the calibration and prediction section.

### **2.1.2 Land use layer**

Firstly, Converting Land use layer from vector format to raster format, then based on the model requirements and the actual situation of the study area, reclassifying them into six categories respectively: urban industrial land, rural settlements, agricultural land (cropland, orchard, etc.), pastures, waters (rivers, lakes, etc.) and unused land (sandy land, saline land, etc.). The land use categories are encoded by integer assigned 1 to 6 in order. Finally, they were transformed into GIF format.

### **2.1.3 Excluded layer**

Excluded layer takes important responsibility to urban growth by setting up resistant factors of urbanization. In SLEUTH, a certain district can be possible or prohibited to be urbanized by Excluded layer. Acting as the weighting layer, the rate of urbanization can be slowed down or altered by changing the resistance factor of urban growth. Allowing classification in the layer by probability of exclusion, the cells' value can be evaluated from 0 to 255. 0 represents the area can be completely urbanized while all values over 100 indicate that urbanization is impossible. (<http://www.ncgia.ucsb.edu/projects/gig>)

With regard to areas delineated by policy and urban plans, such as unprotected wetlands, protected farmland or vegetable plots, values varying from 0 to 100 can be assigned on behalf of urbanization opportunities: the closer the value is to 0, the higher probability of urbanization; the closer to 100, the more unlikely to be urbanized. Hence, Excluded layer plays a significant role in SLEUTH modeling, and by adjusting it, a SLEUTH model can integrate urban planning, policy and other macro elements to forecast urban development from regional perspective.

### **2.1.4 Urban layer**

The Urban layers are determined by digital land use maps, aerial photographs or remote sensing images of different time series. Being the foundation of the self-modified CA model, the urban extent at the beginning year (known as the "seed") is used to initialize the model, and other years (called "control layer") are applied during calibration phase for the least squares calculation to generate the optimal statistic result. Sorted by binary classification, 0 implies non-urbanized areas while urban regions can be any integer values between 1 and 255.



### **2.1.5 Transportation layer**

Transport network has a great influence on the urban sprawl as cities tend to develop from the downtown to the directions along the transportation system. More than one year transportation data should be taken into account to simulate dynamic effects. Values are set in the range from 0 to 255, where 0 represents no road and other values indicate the relative reachability of the network. The transportation layer can be binary (0 or 1), relative weight values such as (0, 1, 2, 4), (0, 25, 50, 100), or the relative accessibility of the road (high, medium, low, none). In this research, a 0-4 classification is used in the Transportation layer. For example, Expressways, the national highways and provincial roads are defined as “main transportation” scaled as 4, railways and secondary roads classified as the “secondary transportation” are assigned as 3, and alleys and trails are classified as 1; non-road cells are evaluated as 0. The value of one street in 2 years may be different.

### **2.1.6 Hill shade**

Seeking for a better spatial visualization rather than participate in the simulation, a shadow layer called “Hill shade” is embedded in the output image as background. Hill shade is usually extracted from the DEM. An immense water area can be superimposed into Hill shade.

## **2.2 Parameters**

The most noteworthy advantage of SLEUTH is that the model has an ability to calculate the optimal combination of coefficients based on the characteristics of the study area. There are five factors manage the behavior of SLEUTH: DIFFUSION, BREED, SPREAD, SLOPE\_RESISTENCE, and ROAD\_GRAVITY, they all varies from 0 to 100.

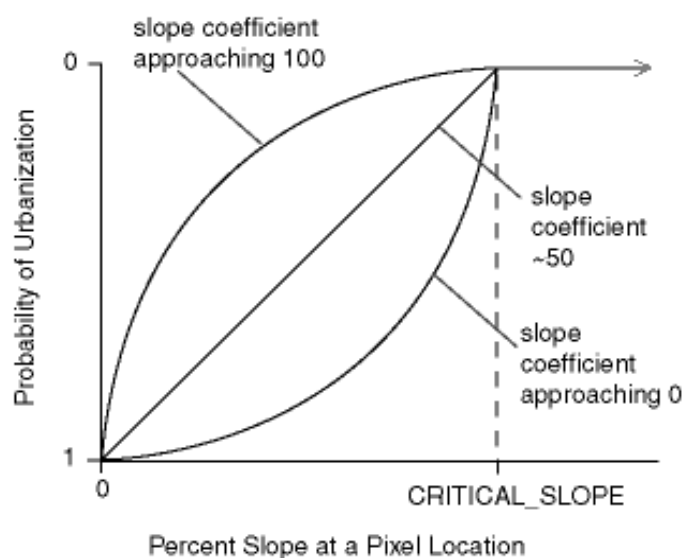
Determining the probability of a random pixel to be urbanized, DIFFUSION controls the entire dispersiveness of detached urban cells generated by Spontaneous Growth. In Road Influenced Growth, DIFFUSION specifies the pixel number and interval moving along road network.

A BREED constraint influences the New Spreading Center Growth and Road Gravity Growth by controlling the probability to become another growth center of a new born urbanized pixel, and the times of a cell moving along a road in the Road influenced growth.

SPREAD is invoked by the Edge Growth, if there is a sprawl center with more than

two urban neighbors in its  $3 \times 3$  surroundings, SPREAD decides the urbanized probability of other cells in the cluster.

Just as Figure 2 presenting, it is more suitable for urban construction when a cell is flatter. The likelihood of settlement extending up steeper slopes is controlled by SLOPE\_RESISTANCE. If a cell's gradient exceeds the CRITICAL\_SLOPE, it will not be developed into urban land. The probability of urbanization in precipitous landscapes is dynamic, which depends on both the proportion of available flat land nearby and the distance to the surrounding urban area. SLOPE\_RESISTANCE has a one-vote veto power in SLEUTH model, that only the slope of a certain position is suitable there can be urbanized, otherwise no matter what the other four factors are, urbanization is impossible. Slope in percentage is not a simple linear relationship with the development of the site but acting as a multiplier. When the coefficient is close to zero, the scope of urbanized proportion changes little. Actual slope value and the corresponding relations with urbanization are shown in Figure 2.



**Figure 2** Sketch map of the relation between slope and urbanization probability

As the most complicated coefficient, ROAD\_GRAVITY attracts new settlement falling within a predefined space along the existing road system. In the Road influenced growth, the coefficient determines the maximum searching distance of a selected pixel.

### 2.3 Calibration

Before urban growth prediction, a particularly demanding step “Calibration” is accomplished by the comparison of simulated urbanization with historical growth to refine the controlling coefficients to the specific study area. The Brute-force method (Hagerstrand, 1965), which is divided into coarse calibration, fine calibration, and

final calibration, is used to predict the urban expansion (Wu F., 2002). Using the Monte Carlo iterations, the ranging extents of five factors are shrinking gradually to achieve the optimal parameters.

Applied in a set of nested loops, calibration of the modified CA is replicating the spatial pattern and extent of historical sprawl and predicting the future by allowing the model to iterate with the same rules continuously. Considered as the “seed year”, the first year in time series contributes to simulate the urban expansion while other historical data thought as “control year” are responsible to narrow the factor space. The spatial resolution is condensed by users in the initial exploration and increased through calibration phases. The top scored numeric combinations corresponding to each sequential multistage optimization refine their range to feed the subsequent calibration as “best settings”. With the calibration completed, the model is being used to generate a set of future scenarios for the study area along with their probabilities.

As the calibration phrase is too complex, we have skipped it and use the result from Feng and her colleagues (Feng Hui-hui et al., 2008): DIFFUSION = 87, BREED = 81, SPREAD = 94, SLOPE\_RESISTENCE =1, ROAD\_GRAVITY = 72. In Feng's forecasting part, only metropolitan area was taken into consideration, in this study we expand the study area to the whole Dongguan including agricultural land.

## **2.4 Urban CA growth rules**

The SLEUTH urban model is developed with sets of predefined growing rules involving Spontaneous Growth, New Spreading Center Growth, Edge Growth, Road Influenced Growth and Self-modification. They are applied continuously to lead the urban simulation to a specific morphology, and the entire cellular space is updated after each rule has been executed.

### ***2.4.1 Spontaneous growth***

The spontaneous growth describes the random urbanization in SLEUTH framework. If the DIFFUSION is greater than the pseudo random number generated in the simulation, any non-urban cell fulfilling the slope constraint has a certain (but small) probability to be urbanized at any times, except that it has been already urbanized or rejected by Excluded layer. A larger diffusion coefficient will produce a relative distributed spread pattern of urban growth.

### ***2.4.2 New Spreading Center Growth***

To allow a new urban cell generated by Spontaneous Growth with a satisfied gradient

to become another spreading center, there must be at least two urban neighbors in the immediately vicinal eight locations (Fig. 3) and BREED is bigger than the pseudo random number. More expanding center will emerge as the BREED ascending.

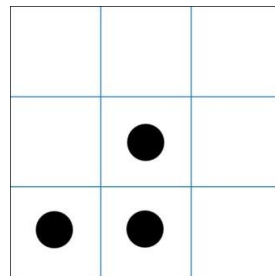


Figure 3 An example of new spreading center growth

### ***2.4.3 Edge Growth***

As a kind of organic growth that replicates the urban expansion into their surroundings, Edge Growth is accepted as the most prevalent expanding type of SLEUTH, tends to be more obvious when the DIFFUSION factor accelerates. Existing growth centers including initial ones and reproductions will prompt a wider band of urbanization outward from their boundaries. Therefore, if there are no less than two urbanized pixels in center's 3 \* 3 neighbors and DIFFUSION is bigger than the randomly drawn number, the left untransformed cells with an appropriate slope will have an overall urbanizing probability. In other words, subjected to SLOPE and DIFFUSION coefficients, it will be possible to urbanize a cell on the premise that three or more settlements locate in its eight neighbors surrounding.

### ***2.4.4 Road influenced growth***

Typically, a cell is more likely to be urbanized when it is located closer to transportation. If the BREED factor of a recent urbanized cell is appropriate and there are streets within the search radius determined by ROAD\_GRAVITY, a cell on the street closest to the urban cell is transformed to a temporal urban cell which is regarded as a new urban sprawl center. It will wander randomly along the adjacent transportation and the ultimate position will be another urban growth center, and the surroundings maybe urbanized.

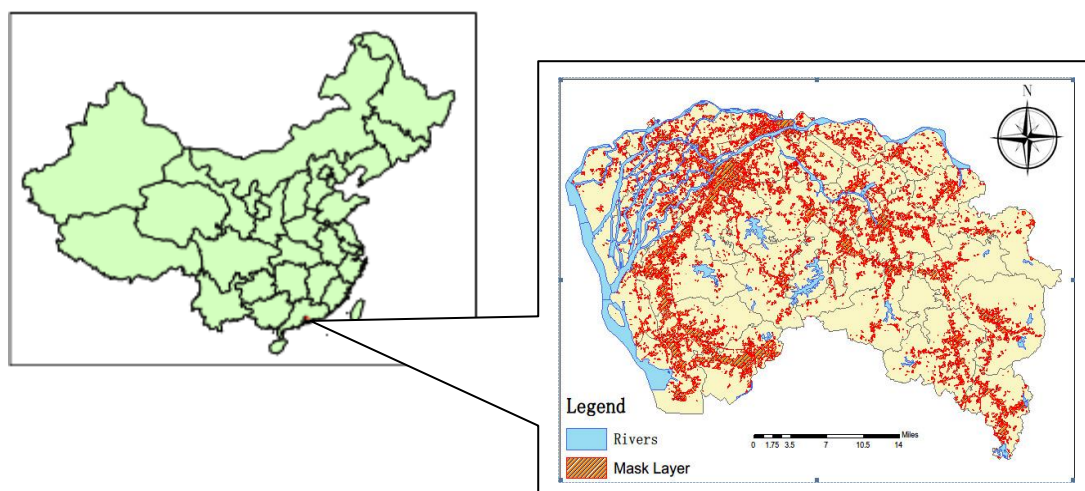
### ***2.4.5 Self-modification***

Since urban expansion is nonlinear, the coefficients of the SLEUTH model are unalterable. By the feedback mechanism, an additional set of rules permitting the

model to modify itself dynamically is defined to simulate the urbanization more realistically by coupling variables.

The control coefficients are able to self-modify so that the CA can adapt itself to the circumstances it generated. It is applied when the absolute amount of growth is extremely high or low. During urban explosion, which usually occurs in the early growth cycles when there are masses of cells available to be urbanized, if the growth rate of this cycle exceeds the maximum threshold, each coefficient will be multiplied by a number greater than 1 to improve the expansion to prosperity (Boom); as soon as urban density levels off, the sprawl speed drops consistently below the minimum threshold (CRITICAL\_LOW), all variables have to be reduced by multiplying a number less than 1, which results in stagnation (usually at the end of the urbanization) gradually and shows a “Bust” condition like a depressed or saturated system. Self-modification is so significant to estimate the typical S-curve growth because without its cooperation, mistakes of a linear or an exponential growth will be made.

## 2.5 Study area and data



**Figure 4** Location and administrative districts of Dongguan municipality in China

There are two maps in Figure 4. On the left is the Map of China shows the Dongguan metropolitan area (22°39′–23°09′ N, 11°30′–11°40′ E) that is located in the east coast of Pearl River Estuary, south-central part of Guangdong Province, Southern China (Yearly Inventory of Guangdong Province, 2007). On the right side is the Map of Dongguan and we can see the general landscape. The total land of the municipality is 2465 km<sup>2</sup> with a maximum north–south length of 46.8 km and east–west distance of 70.45 km, hilly platforms and alluvial plains are its major topography tilted from east to west. With the fabulous location advantages adjacent to Guangzhou and Hong Kong, the level of urbanization in 2000 is up to 82% and the total population reached 644.58 million, of which 490.14 million are transient population mainly consisted of rural migrant workers. This prospective city is highly industrialized and urbanized towards “Factory of the World” (Hong S., 2003).

**Table 3** List of data sources used in the study

Data type	Year	Name	Resolution/Scale
	1997	Landsat TM	30 m
	2001	Landsat TM	30 m
	2005	Landsat TM	30 m
	2009	Landsat TM	30 m
		DEM	30 m
	2005-2015	Master plan of Dongguan	1:50000
	2008	Dongguan's land use map	1:350000
Vector	2008	Land use data of Guangdong	1:100000
	2010	Land use data of Guangdong	1:100000
Statistic	2010	Guangdong year statistic book	-----

Data in Table 3 applied in the project include 1997, 2001, 2005 and 2009 TM images of Dongguan, the digital elevation data (DEM), and the administrative divisions of the Pearl River Delta region in \*.shp format, Statistical Yearbook of Guangdong Province. Under the help of ArcGIS and IDRISI, after a successive RS image processing steps, we achieve 4 years Urban and Transportation layers (Fig.5), 2 distinctive Land use layers, an Excluded layer derived by main rivers and lakes and a Slope layer in percentage generated from DEM.

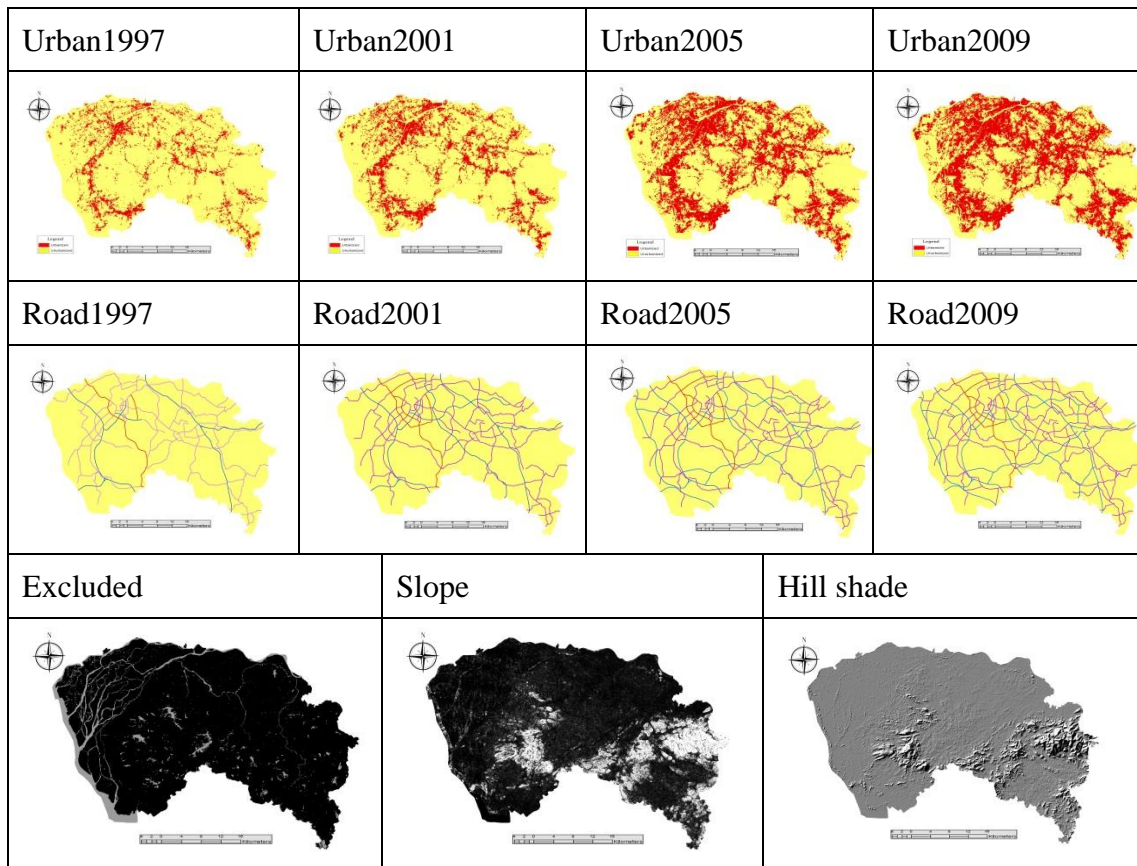


Figure 5 Input data layers of SLEUTH

### 3. Results and discussion

#### 3.1 Historical urban growth simulation

The simulated urban land distribution can be verified by shape index Lee-Sallee, which reflects the morphology similarity between actual situation and corresponding simulation of the study area (Tokens P. M., 2003).

$$\text{Lee-Sallee} = (A \cap B) / (A \cup B) \quad (1)$$

A = simulated urban land distribution B = urban land distribution in reality

The Lee-Sallee index of three control years 2001, 2005 and 2009 are 0.5429, 0.5594 and 0.5919 respectively. Based on the research of Silva in 2002, it is reasonable when the index is above 0.54 (Silva, 2002), the parameters are suitable for our study area.

Area index representing the ratio of urban area between simulation and actual data is also used to evaluate the model.

if ( AS < AA )

$$\text{Area-Ratio} = AS / AA$$

else if ( AS > AA )

$$\text{Area-Ratio} = 2 - (\text{AS} / \text{AA})$$

AS = urban land area in simulation    AA = urban land area in history (2)

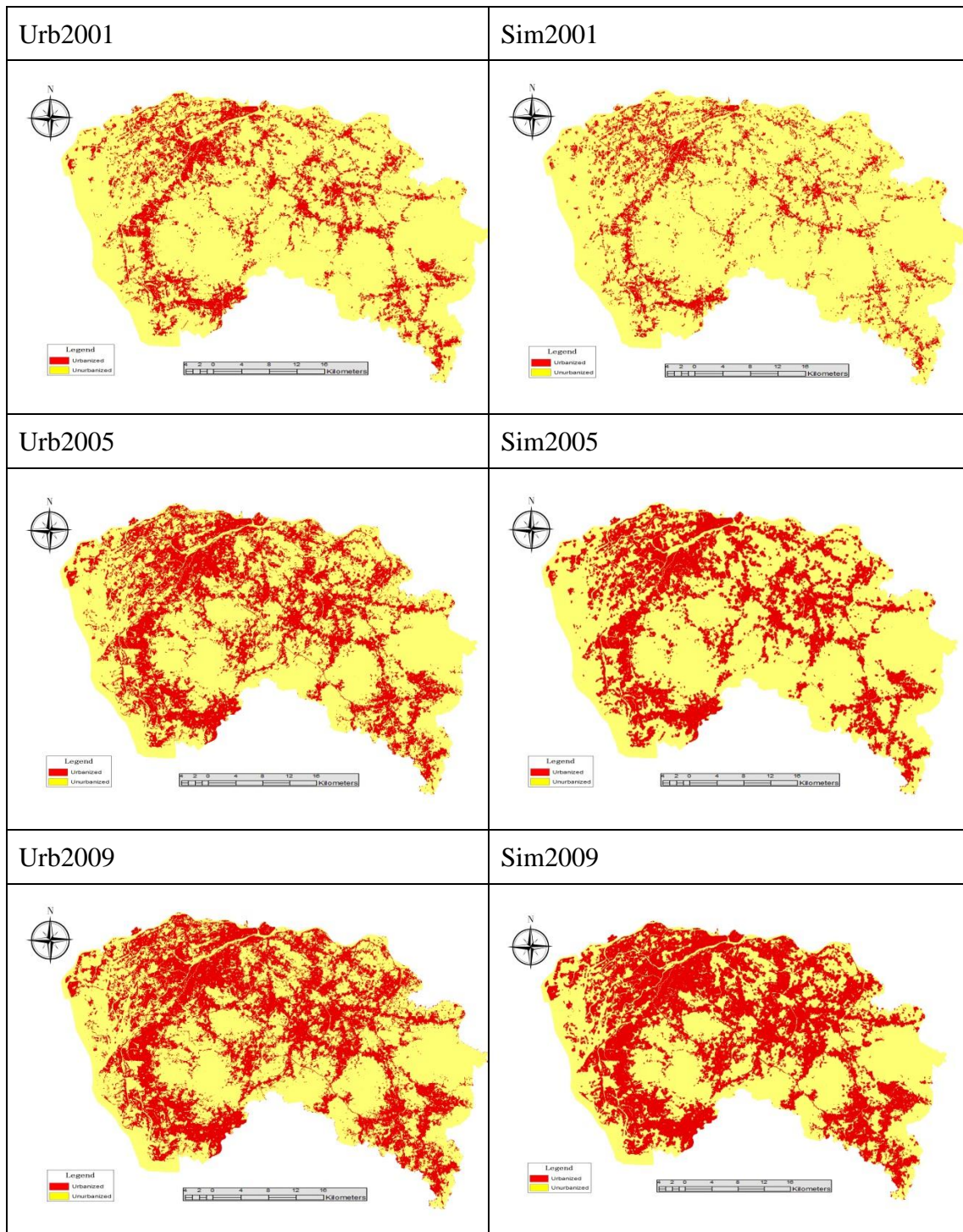
The Area metrics of three control years are 92.10%, 93.98% and 94.80%. It indicates outputs perform very well in the total urban area simulation, which has a better fitness than Lee-Sallee, the urban morphology.

The optimal coefficient set also represents the essential urban sprawl characteristics of Dongguan Municipality:

(1) SLOPE\_RESISTENCE is 1 means the topography of Dongguan has little influence on the urban expansion. Other four factors are all very big and SPREAD almost reaches the maximum value, which refers that all four growing rules (Spontaneous growth, New spreading center growth, edge growth and Road influenced growth) are at almost full speed. It is quite reasonable as the economy of Pearl River delta region has been developed dramatically since the Reform and Open policy put into implement three decades ago. Especially from 1990s, the urbanization rate keeps accelerating beyond our expectation that even regions not appropriate to be urbanized has transformed to build-up places.

(2) As showed above, as the parameters are range from 0 to 100, it can be inferred that both the DIFFUSION (87) and SPREAD (81) are very high. Consequently, cells are much easier to be urbanized with a scattered geographic distribution during urban expansion, which indicates urban land use of Dongguan is experiencing a severe extensive development; such as urban extent is unlimited outward expanded as well as urban morphology is distributed universally instead of aggregation. For example, the urbanization mainly occurs in rural area surrounding villages which are separated from each other, so on the simulating images, we can see lots of growth centers.





**Figure 6** Comparison between history and simulation of 3 years

The historical maps in Figure 6 are derived from Feng's research (Feng, et al., 2008). The simulated urban land maps illustrate that Edge growth and Road-influence growth play a key role in urban sprawl. In 1997, the urbanization level of Dongguan is not very high that the urban sprawl mainly accures around existing urban growth centers and expands along transport network (Turner B.L., Meyer W.B., 2004). Different from other cities with one or several centers in China, Dongguan has a “collection of city cores” where 28 towns are highly urbanized and independent from each other. Because of the unique “group metropolitan” structure, Dongguan is

fragmentary that most towns have their own residential, industrial and commercial centers such as luxury hotels, shopping malls, etc..

At the beginning of 21<sup>st</sup>, the commercial real estate frenzy swept China. As the industrial heart of Pearl River Delta, Dongguan has been rapidly urbanized and isolated growth centers has been springing up in rural parts. From then on, Edge growth based on new urbanized cells and centers impact Dongguan dramatically. Until 2009, the urban area used to be separated before are much gathering together, for example, there are much more build up area in the northwest of Dongguan, especially where the municipal government is located.

During the past twenty years, Dongguan has experienced industrialization mainly by foreign investment. There has been a rapid bottom-up urbanization process from central urban areas to towns and villages. The real and simulated urban area growth of three periods, 1997 to 2001, 2001 to 2005 and 2005 to 2009 are presented in Table 4. Compared with real growth data, all of the simulations are more or less overestimated. The overestimation is mainly in the northeast part with a relatively flat topography. That is because the Excluded layer only extracts the trunk rivers and lakes, urban growth simulation cannot avoid the main northeastern surface features such as stagnant water area, the East River Alluvial Delta Plain, a large number of high-quality paddy fields and agricultural land.

**Table 4** Urban growth of 1997-2001, 2001-2005 and 2005-2009 in Dongguan

	1997-2001	2001-2005	2005-2009
Growth of real urban pixel number	<i>70,060</i>	<i>143,851</i>	<i>63,427</i>
Growth of simulated pixel number	<i>122,150</i>	<i>181,289</i>	<i>85,404</i>
Growth of real urban area(km <sup>2</sup> )	<i>63.05</i>	<i>129.47</i>	<i>57.08</i>
Growth of simulated urban area(km <sup>2</sup> )	<i>109.94</i>	<i>163.16</i>	<i>76.86</i>

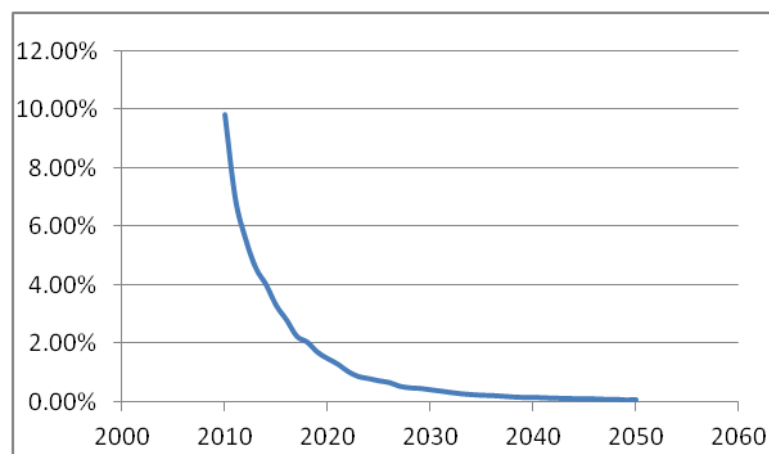
### 3.2 Future Urban growth prediction under different scenarios

SLEUTH is applied for establishing optimal urban planning scenario to predict and evaluate urban expansion under different conditions (Tokens P. M., 2003), such as government policy intervention, urban planning guidance, foreign investment and other issues. There are two prediction types of SLEUTH model. The first approach keeps the parameters be the same as history: if future circumstance remains stable as historical trajectory, the urban growth will be a continuation of the past development, the optimal parameter set obtained from the previous stage can be applied directly for prediction; the other approach changes the parameters and there are two situation: if the external environment changes in following decades, some appropriate

modifications of the optimal coefficients are needed to meet the requirements (Wu F., 1998), alternatively, the Exclusion layer can be adjusted, for example, coupling future urban development policies and urban planning strategies with the Excluded layer, and combining forecasting trends in specific scenarios.

### 3.2.1 Urban growth prediction in historical scenario

In this chapter, the first aim is to choose a time duration when the urban area is expanding most dramatically. The five parameters are not changed and a historical scenario from 2010 to 2050 is built up based on the hypothesis that the urbanization process is stable as before. Urban growth speed is predicted in Figure 7 that shows Dongguan is under rapid urbanization. During the 40 years, expansion keeps on but the speed is decreasing generally. From 2030, urban extent tends to be steady then reaches saturation in 2050. Considering the urban sprawl mainly takes place in 2010 to 2030, we choose this period to predict future urban growth in Dongguan generally.



**Figure 7** Urban growth speed prediction of historical scenario from 2010 to 2050 (%)

As a result of the remarkable morphology including 28 towns scattering within its administrative region and a high DIFFUSION parameter, there are not many urbanization constraints in Dongguan. On the other hand, the loose city structure leads to a separated distribution of residential districts (Goldstein, 2004) that reduces the efficiency of the infrastructure. For example, if a residential district is adjacent to another, they can share hospitals, schools, supermarkets, parks etc. in the surroundings together. On the contrary, isolated growth centers, which make settlements too far away from each other, will raise a risk of expropriating agriculture and forestry land as infrastructure (Turner B.L., Meyer W.B., 1994). Rural area, which is regarded as the “lungs of the city” including cultivated lands, pastures, woodlands etc., is usually situated between different city centers. As we all know, city

is not only responsible for dwellers' basic necessities of life but also provides fresh air and clear ecological environment. A fragmented urban morphology like Dongguan may result in an irreversible decline in rural area as adjacent urban patches tend to combine together.

The historical trajectory of urbanization tends to expand unlimitedly in all directions, which squeezes arable lands on the boundary, especially along roads and railways artery. The two dominant expansion, Edge Growth and Road Influenced Growth, impact urbanization of Dongguan dramatically, which may aggravate the "pie-style" of the city.

**Table 5** Land use and transformation in Dongguan from 1985 to 2000

Dongguan	1985 (km <sup>2</sup> )	Compare with total area (%)	2000(km <sup>2</sup> )	Compare with total area (%)	Variation (km <sup>2</sup> )	Variation (%)
Cultivated land	851.745	34.51	676.031	27.39	-175.714	20.63
Forest land	854.576	34.63	751.925	30.47	-102.651	-12.01
Grass land	89.679	3.63	81.821	3.32	-7.858	-8.76
Water body	313.158	12.69	322.647	13.07	9.489	3.03
Urban construction	47.264	1.92	94.488	3.83	47.224	99.92
Other construction	40.948	1.66	41.581	1.68	0.633	1.55
Rural non-farm land	268.739	10.89	497.617	20.16	228.878	85.17
Spare land	1.924	0.08	1.924	0.08	0	0

Data from : Resources and Environment, Chinese Academy of Sciences Center

In Table 5, all agriculture land types have been reduced from 1985 to 2000, especially cultivated land. The substantial urbanization of "decentralized concentration" (Rafiee R. et al., 2009) rapidly occupies surrounding rural area along the main thoroughfares. Attached to native land and unwilling to leave it, which is considered as the most typical Chinese developing style, the "decentralized concentration" impedes the gathering of urbanization in space (Raucoules D., 2003). Rural industry is significantly affected by Land Collective Ownership, which makes industrial centralization more difficult. The industrial fragmentation limits the land output rate per unit area to 2,486,170 million yuan /m<sup>2</sup>; significantly lower than 3612.803 yuan /m<sup>2</sup> of Guangzhou and 9676.504 yuan /m<sup>2</sup> of Shenzhen (ZHENG Yan-Ting, 2003). Urban area is expanding rapidly in a broken spatial pattern, the export-oriented economy formulates a typical "urban village" that poor living conditions are mixed with industrial area.

### 3.2.2 Urban growth comparison with different parameter sets

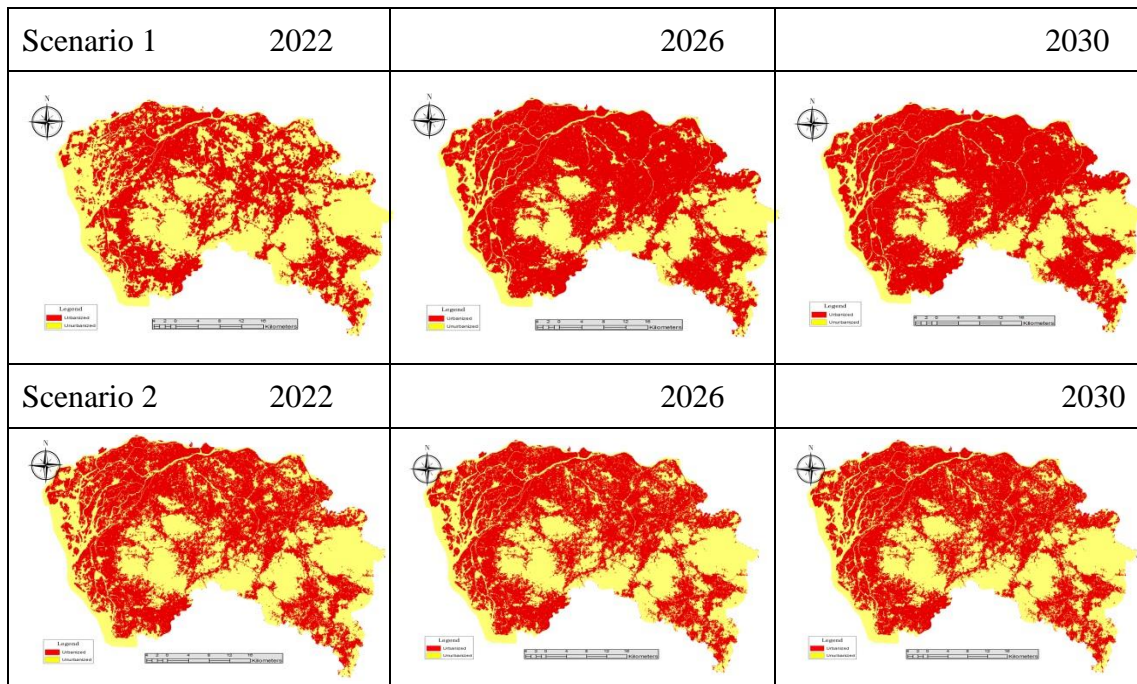
In the previous part a historical scenario is described, the five parameters controlling the SLEUTH model are set as DIFFUSION = 87, BREED = 81, SPREAD = 94, SLOPE\_RESISTENCE =1, and ROAD\_GRAVITY = 72 to predict the urban sprawl along the historical trend. In order to analyze the influence of urban planning on future urban growth of Dongguan, another scenario is set to compare the difference (Wu F., 2000). In the adjusted scenario, DIFFUSION and SPREAD are reduced by 50% to slow down the urbanization and build a more concentrated urbanization.

In 3.2.1, we set 2010 to 2030 as the general aim research duration, as the SLEUTH model needs at least 4 years data in a prediction, we finally choose 2018-2022, 2022-2026 and 2026-2030 as the study period.

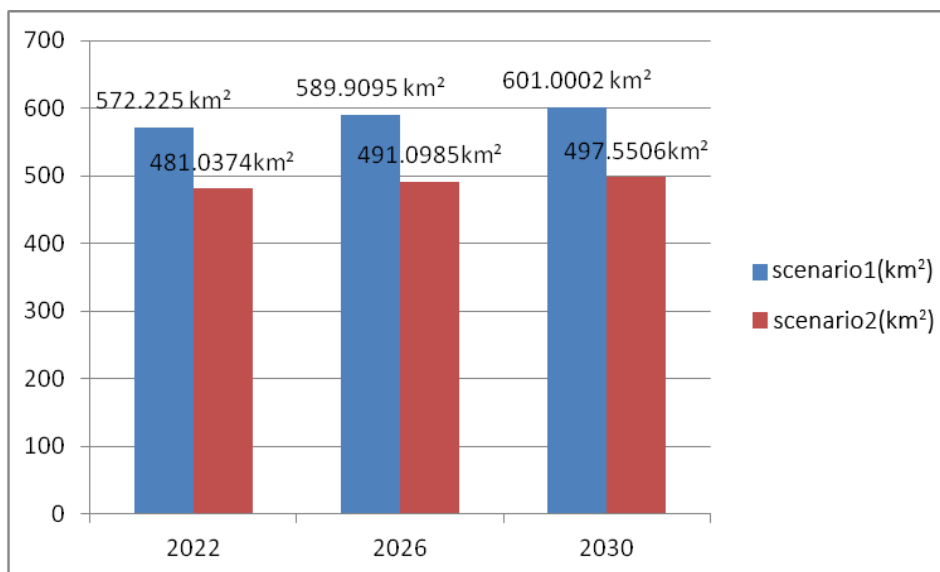
**Table 6** Urban growth prediction of 2018-2022, 2022-2026 and 2026-2030 in Dongguan

	2018-2022	2022-2026	2026-2030
Growth pixel number under historical scenario	92,645	54,578	34,233
Growth pixel number under adjusted scenario	50,367	31,056	19,911
Growth area under historical scenario (km <sup>2</sup> )	83.38	49.12	30.81
Growth area under adjusted scenario (km <sup>2</sup> )	45.33	27.95	17.92

The urban growth area of 2018-2022, 2022-2026, and 2026-2030 of both scenarios are presented in table 6. It indicates that the city is expanding continuously but the expansion area of three periods keeps shrinking, especially a sharp drop in 2022-2026. Urban expansion will continue in future but the speed sharply inclines to approach its maximum extent around 2030.



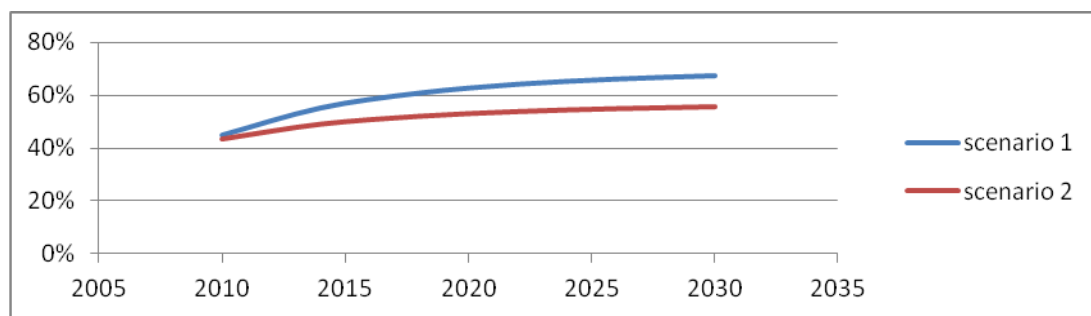
**Figure 8** Prediction under different scenarios of three periods  
 (Scenario 1 = historical scenario; Scenario 2 = adjusted scenario)



**Figure 9** Total urban area (km<sup>2</sup>) of different scenarios  
 (blue = historical scenario; red = adjusted scenario)

Based on the real data of 2009, urban sprawl of 2022, 2026 and 2030 are predicted respectively under historical and adjusted scenarios (Fig.8, Fig.9). Urban area keeps expanding during the research interval under both scenarios. Under the adjusted scenario, urbanization is downscaled comparing with the historical scenario. As

DIFFUSION is set to half of historical simulation, the total urban area of scenario 2 is obviously less than scenario 1 as the urbanized probability of a random pixel is decreased to 50% of history. As SPREAD is also adjusted to half of scenario 1, cells within the cluster of a spreading center are more difficult to be urbanized by Edge Growth. As most urbanization process is invoked by Edge Growth (Clarke K.C., 1993), urban cells generated from scenario 2 are not as many as scenario 1. Spontaneous Growth controlled by DIFFUSION also restricts the overall distribution of urban cells in scenario 2 that the urbanization in the adjusted scenario is not as dispersive as historical scenario (White R. & Engelen G., 1993).



**Figure 10** Level of urbanization in percentage under different scenarios  
(blue = historical scenario; red = adjusted scenario)

The urban density (urban area compared with the total in percentage) of 2022, 2026 and 2030 in figure 10 are 64.20%, 66.19%, 67.43% and 56.0%, 57.1%, 57.8% respectively, which implies that both of the two predictions have a high level of urbanization. Compared with the historical urbanization records of 1997, 2001, 2005 and 2009 which are 12.8%, 19.9%, 34.7% and 40.1%, it can be concluded that Dongguan has been urbanizing at an incredible speed in the coming 20 years.

## 4. Conclusion

Promoted by economic internationalization since Reform and Open of China in 1978, Dongguan' export-oriented economy is developed at tremendous pace to an average annual growth of 20% by attracting foreign investment. Rapidly economic growth accelerates the specific "rural industrialization" and "rural urbanization" in Chinese style that industry, land, population and other economic factors are distributed as scattered layout, which becomes an important constraint to future competitiveness(Wu F., et al., 1997).

In addition, as the Excluded layer of SLEUTH used in the study does not involve cultivated land protection, the vegetation adjacent to urban edge has been swallowed substantially by urban construction, and the agricultural land in the southeast corner

of Dongguan will disappear at the end of 2030. Therefore, future land use planning should emphasize farmland protection to avoid the urbanization taking over high-quality farmland too much.

The economic scale and population of Dongguan have already exceeded the average level of Chinese mainland small and medium-sized cities (Tokens P. M., 2003). The industrial structure has already formulated a unique prototype. As a remarkable representative of the semi-urban pattern in China, different strategic choices will lead to totally different consequences, in order to promote the urbanization comprehensively; future urban planning should completely reinvent "urban village" as well as appropriate relocation to integrate the use of land resources at the same time extensively spreading industrial park economic.

Based on above analysis, Edge Growth is the dominant force of Dongguan's urbanization during 2022-2030; regions adjacent to growth centers are more likely to be urbanized than remote area in general. Rapid urban expansion takes up large amount of other land types, around 2030, Dongguan's urbanization will reach the critical state in spatial as well as it will sharply decline comparing with the previous decades. Unlike excessive growth rate in scenario 1, the urbanization speed is obviously more reasonable and sustainable in scenario 2, which confirms SLEUTH urban model is a good assistant of urban planning to avoid willful expansion with a scenario forecast. To protect ecological environment and promoting sustainable development of the region, relevant decision makers should take effective strategies to control urban sprawl. By the set of forecast scenarios, SLEUTH can certainly predict future urban development as an auxiliary to urban planners and government.



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