

THE SIMULATION OF URBAN GROWTH APPLYING SLEUTH CA MODEL TO THE YILAN DELTA IN TAIWAN

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ABSTRACT *The SLEUTH model developed by Clarke, based on the Cellular Automata (CA) city expansion development theory, can be applied to city development simulation in metropolitan areas. If we want to predict urban development trends, many microcosmic changes of parameter can cause major changes in the predicted result due to the complexity and indefinite nature of parameters. The SLEUTH model has been applied to the Silicon Valley of San Francisco and in Washington D.C. In fact, there have been good results applying this method in other countries such as Australia, Vietnam, Egypt and Portugal. In this study we explore the simulation of urban growth applying SLEUTH model to three cities: Yilan, Luodong and Suao in the Yilan Delta area of northeast Taiwan to study the dynamics of the region using historical data. After carrying out the SLEUTH prediction method, we found that the result of its application for predicting city development in the Yilan Delta area shows that the cities of Yilan and Luodong are developing and expanding more evenly from the city center, partly because of their large dockland areas, while Suao city has expanded only along the main road, due to the limit of the steep mountain slope inland. However, if one wants to improve the dependability of the prediction, one must consider the influence of fast changes in urban social systems in Taiwan.*

Keywords: Cellular Automata (CA), Urban Growth Model (UGM), Urban Expansion

Introduction

Urbanization is one of the most evident global changes. In the last 100 years, the population of Taiwan has increased tremendously and land use has changed dramatically. The urban growth trend of different regions in Taiwan is a question that is well worth probing into, especially cities in the Yilan Delta area of northeast Taiwan, which are isolated by surrounding mountains and have been growing rapidly in recent years due to improvements in transportation and communication.

After the restoration of Taiwan, in 1950, the Taiwan government established the county of Yilan and used Yilan as the administrative center. A series of transportation

and economic policies led to the development of the county. In 1952, the Taipei-Yilan highway, an important communication between the cities of Yilan, Ping Lin and Taipei, was completed. In May 1960, the Central Cross-Island Highway was completed, improving communications between the east and west coasts. At the same time, a branch road of the Central Cross-Island Highway, between Lishan and Yilan was opened for the purpose of developing the logging industry in the forest of Qilan. The North Cross-island Highway was opened in 1966, improving communications between Taoyuan and Yilan Counties, and leading to development of the forestry industry in Taipingshan. To reduce pressure on an overcrowded Keelung Port, the largest in Northern Taiwan, and to develop the Yilan Delta area, Suao Port was opened in 1978. The Northeast Coastal Highway was finished in 1979 to serve the port of Suao and became an important artery for communication.

In 1980, the North Line of Taiwan's railway network made communication between Taipei and Hualien still more convenient. Two way tracks were laid in 1985, and the tracks were electrified in 2000, reducing commuting time and increasing the volume of cargo which could be shipped.

In the early years after 1949 when Taiwan was returned from Japan, Yilan was already the biggest city in the Lanyang Delta. At this time, Luodong began to grow rapidly, due to the development of the logging industry at nearby Taipingshan, which reached its peak in the 1950s and 1960s. When, in the 1980s, the forest resources were depleted, business collapsed at Taipingshan and many workers moved out the area in search of work elsewhere, causing the population of the Luodong area to decrease.

The population of Suao also decreased greatly, due to the development of Suao Port not reaching expectations, and the fact that the North Line railway bypassed the town, which was connected to the main line only by a branch line. Population changes in Yilan, Luodong and Suao between 1964 and 2002 are shown in Figure 1.

The dynamic and spatial modeling of urban growth permits systematic and formal studies of possible future developments and provides a basis for the preparation and

evaluation of urban policies. Using a model of urban growth allows the user to obtain a better insight into actual decision making, thus allowing the user to forecast alternative and comparable future states (Leao, 2004). If we collect the historical urban development parameters and use them to predict the future development trend of a city, this will contribute to the government's planning and policies regarding city development.

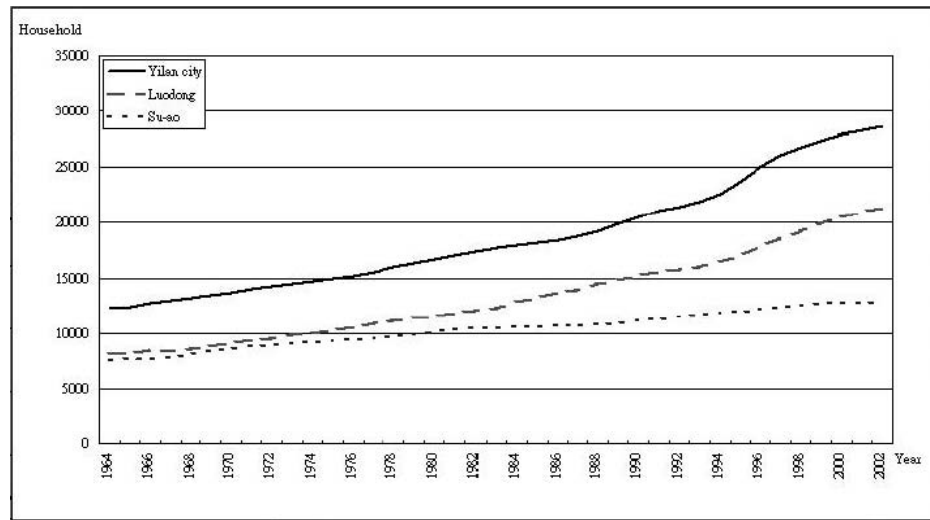


Figure 1: Population changes in Yilan, Luodong and Suao between 1964 and 2002

The rapid development of GIS helps to foster the application of Cellular Automata (CA) in urban simulation. CA modeling is one of the recent advances in spatial-temporal modeling techniques in the field of urban growth dynamics. A number of CA-based models of urban growth have produced satisfactory simulations of spatial urban expansion over time.

The aim of applying the SLEUTH urban growth model to the Yilan metropolitan area is to simulate and predict its urban development. We intend to simulate and predict the different results of urban expansion types caused by different geographic environments and historical factors in the small and isolated area of Yilan's Lanyang Delta.

By using different urban growth parameter factors we want to study how the urban growth types are different from each other in Yilan, Luodong and Suao, three big metropolitan cities in the Lanyang Delta area. We aim to see which kind of urban growth types each city belongs to: whether of the outward expansion from the city center type or of the expansion obstructed by mountainous terrain kind, and which city promises to develop faster in the future.

Cellular Automata And Urban Growth Model

CA is a GIS simulation method that can be applied to city development simulation. The SLEUTH model developed by Clarke, based on the CA city expansion development theory, can be applied to city development simulation in metropolitan areas (Clarke, 1997). If we want to predict urban development trends, many microcosmic changes of parameter can cause major changes in the predicted result due to the complexity and indefinite nature of the parameters. The SLEUTH model has been applied in the US to the Silicon Valley of San Francisco and Washington/Baltimore (Clarke et. al,1998), and to Atlanta metropolitan area (Yang, et. al, 2003), and in China to the Zhujiang Delta (Weng, 2001) and the Wuhan City Yangtzi River area (Cheng, 2004). In fact, there have been good results applying this method to many developing nations, such as Porto Alegre City, Brazil (Leao, 2004), Vietnam, Egypt and Portugal.

The urban growth model (UGM) has successfully demonstrated the applicability of integrating historical maps with remotely sensed data and related geographic information to model spatial urban dynamics. A typical Cellular Automata consists of four primary components: cells, states, neighborhoods and transition rules. Cells are the smallest units of allowed states. The states of a cell can change in relation to its neighboring cells when a set of transition rules is applied uniformly. In order to improve the simplicity of CA model construction, its main weakness, many efforts have been made particularly in the modification and expansion of transition rules to include hierarchy, self modification, probabilities expressions etc. (Yang, 2003).

There are five factors which control the behavior of the model: diffusion factor, breed coefficient, spread coefficient, slope coefficient, and road-gravity factor. There are four types of growth in the model: spontaneous, diffusive, organic, and road influenced growth. The relationship between these five factors and four possible types of growth is shown in Figure 2.

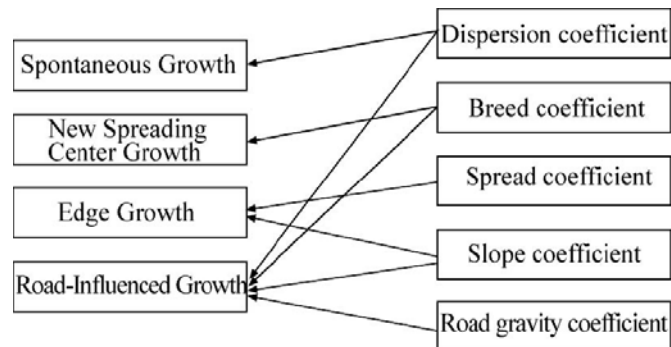


Figure 2: The relationship between five factors and four types of growth

The diffusion factor determines the overall outward dispersive nature of the distribution. The breed coefficient specifies how likely a newly generated detached settlement is to begin its own growth cycle. The spread coefficient controls how much diffusion expansion occurs from existing settlements. The slope resistance factor influences the likelihood of settlement extending up steeper slopes. The road gravity factor attracts new settlements toward and along roads. The SLUEUTH model has six input layers: Slope, Land Use, Excluded, Urban, Transportation and Hill Shade, and is controlled by diffusion (diff), breed (brd), spread (sprd), slope resistance (slp), and road gravity (rg), five parameters.

Spontaneous growth occurs when a randomly chosen cell falls in a stable location for urbanization at the boundary of an existing settlement, simulating the fragmenting influence urban areas have on their surroundings. Diffusive growth permits the urbanization of cells which are flat enough to be desirable locations for development, even if not near an established urban area. Organic growth spreads outward from existing urban cores, representing the tendency of all urban areas to expand. Road

influenced growth encourages urbanized cells to develop along the transportation network, reflecting increased accessibility (Clark, 1998).

Model Description

The study area is located in the Lanyang Delta area of northeast Taiwan. For the past three decades, Yilan area has been one of the fastest growing metropolitan areas in Taiwan as it became the bridge between Taipei, the capital, and the east coast of Taiwan. The location of the study area is shown in Figure 3.

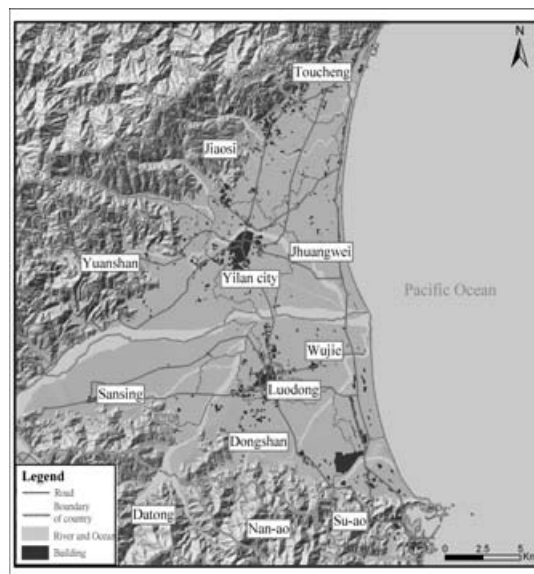


Figure 3: Study Area of Yilan, Taiwan

The study area includes the cities of Yilan, Luodong and Suao in the Lanyang Delta. The definition of the study area isn't based on the administration boundary, since it does not affect urban development range. Therefore we have included suburban settlements in our study area.

Yilan City is the seat of the Yilan County Government, located on the north bank of the Lanyang River, in the north of the Lanyang Delta, and is the largest city in the county, with a population of 92,097 (as of 2002). Luodong is the most important town

to the south of the Lanyang River, in the center of the delta, and the second largest city in Yilan County, with a population in 2002 of 70,258. Suao, a fishing port situated at the extreme south tip of the Lanyang Delta, is surrounded on three sides by mountains and on the fourth side by the sea. Its population in 2002 was 45,469.

Input data for the model's calibration and initial use in prediction came from historical maps and aerial photos, analogue and digital maps for different time periods. There are five map layers to be used in the model. The slope layer and hill shade layer, which is used as a background layer, are created from the 1980 forty meter digital terrain model (DTM) Aerial Survey Office, Forestry Bureau of Taiwan. The Urban layer and the Transportation layer are created from 1964, 1974 DMA U.S.A. and 1984, 1995, 2002 Ministry of the Interior, Taiwan, Yilan, Jiaosi, Sansing, Suao 1/50000 topographic maps. The Resistance Developing Area layer is created from the 1998 map, Constriction and Planning Agency, Ministry of the Interior, Taiwan. The data resources of input layers are shown in table 1. The year 1964 was used as the initial conditions or seed year.

Table 1: The Input Layer of the SLEUTH Model

Layer Name	No.	Year	Data Resources
Hill shade	1	1980	40 meter DTM from Aerial Survey Office, Forestry Bureau
Slope	1	1980	40 meter DTM from Aerial Survey Office, Forestry Bureau
Resistance Developing Area	1	1998	Constriction and Planning Agency, Ministry of the Interior
Urban	5	1964,1974,1984,1995,2002	1964 1974 1/50000 Yilan, Jiaosi, Sansing, Suao Topographic map, (DMA, USA) 1990, 1995, 2002 (Ministry of the Interior)
Transportation	5	1964,1974,1984,1995,2002	1964, 1974 1/50000 Yilan, Jiaosi, Sansing, Suao Topographic map, (DMA, USA) 1990, 1995, 2002 (Ministry of the Interior)

The list of urban areas for Yilan, Luodong and Suao from 1964, 1974, 1990, 1995, and 2002 is shown in table 2. During the period 1960 to 2000, the urban area of Yilan increased 8 times as Luodong increased 7 times.

Table 2: Area of Urban-Historical Data (Unit: Km²)

Year	Yilan	Luodong	Suao
1964	3.2608	3.2768	2.3216
1974	3.5104	5.3808	2.4304
1990	16.0336	11.904	4.4656
1995	16.6768	12.0256	4.4656
2002	24.6048	20.2864	5.4624

In the SLEUTH model, the four elements which influence urban growth are: slope, resistance developing area, urban and transportation. In this research, we use five different years of map data from the Yilan Delta: 1964, 1974, 1990, 1995, and 2002, at a scale of 1:50000. The pre-process of each map layer is described as follows:

- a) Slope Layer: use forty meter DTM file, transform into raster form.
- b) Resistance Developing Area Layer: use WEBGIS local project data provided by the Ministry of the Interior, including seacoast reserves, restricted development areas, combine and transform into raster form.
- c) Urban layer: use ARCMAP to digitize into a vector form and then transform into raster form.
- d) Transportation Layer: as Urban Layer, above.

The first step is to run SLEUTH model calibration, then run model prediction. On computation stage, there are diffusion (diff), breed (brd), spread (sprd), slope resistance (slp), and road gravity (rg), five parameters. Parameters range from 1 to 100. The Urban and Transportation layers are created using maps from four different years. After processing, the model produces one set of best coefficient data and one set of calibration coefficient data which was collected from 1990 and 1995 in our case. Based on calibration data, we can predict the future trend of urban growth.

Results

After applying the SLEUTH urban growth model to Yilan city, Luodong town and Suao town to simulate and predict the urban development in Yilan metropolitan area, we can predict and study the different results of urban expansion types caused by different geographic environments and historical factors. The urban growth parameter results from a simulation process clearly show that the urban growth types are different from each other in these three urban areas. The major urban growth of Yilan city and Luodong town are of the outward expansion from the city center type, while Suao town expands by following the major roads, due to obstruction by mountainous terrain.

After processing the model, we obtain the parameters of best coefficient data and fit coefficient data which can be seen in Table 3. From this table we can see the urban expansion in Yilan City is a mixture of spread and road gravity expansion. The urban expansion of Luodong is mainly by spread, but is resisted by slope. The reason for the urban expansion of these two cities is probably due to the government using both as centers for local development. The function of Yilan city is as an administrative center and a center for culture. Luodong is a center for light industry such as logging, and therefore attracts workers from the surrounding countryside. By contrast, the expansion of Suao is by breed and road gravity expansion, but strongly resisted by slope.

Table 3: List of Parameters for Model (B.C. = Best Coefficient, F.C. = Fit Coefficient)

	Yilan City		Luodong		Suao	
	B.C.	F.C.	B.C.	F.C.	B.C.	F.C.
Diffusion	5	7	10	14	10	10
Breed	5	7	10	14	52	53
Spread	35	51	35	51	7	7
Slope Resistance	45	24	82	56	88	70
Road Gravity	82	84	20	23	46	47

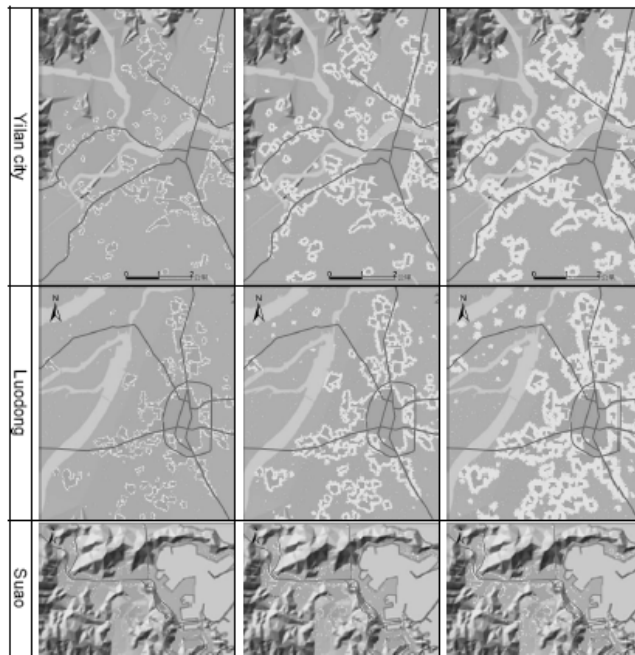


Figure 4: Predicted Urban Growth of Yilan city, Luodong and Suao (Dark gray: Urban Area in 2002, white: Increased Area of Prediction)

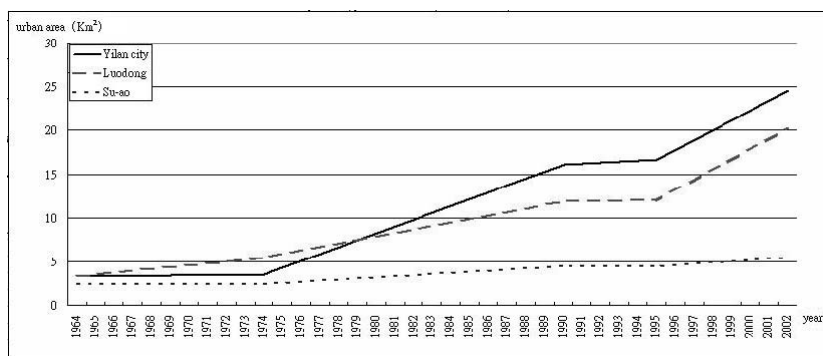


Figure 5: urban area change in Yilan, Luodong and Suao between 1964 and 2002

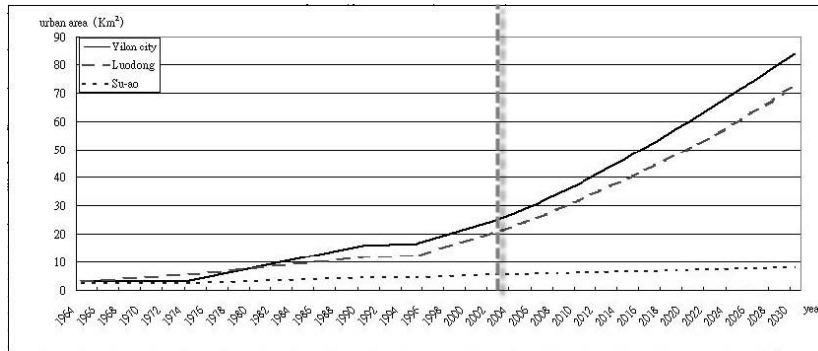


Figure 6: Predicted urban area change in Yilan, Luodong and Suao between 2002 and 2030

Table 4: Predicted Urban Area Data (Unit: Km²)

Year	Yilan city	Luodong	Suao
2005	28.9648	24.2416	5.6768
2010	37.8864	31.9072	6.1488
2015	48.3056	40.5632	6.5824
2020	59.7056	49.9200	7.0704
2025	71.4992	60.5872	7.5824
2030	83.7136	72.5184	8.0576

Conclusion

In this study we explore the simulation and prediction of urban growth, applying SLEUTH model to three cities: Yilan, Luodong and Suao in the Yilan Delta area of northeast Taiwan to study the dynamics of the region using historical data.

- a) The urban growth parameter results from a simulation process clearly show that the urban growth types are different from each other in these three urban areas. From Figure 4, we can see the major urban growth of Yilan city and Luodong town are of the outward expansion from the city center type, while Suao town expands by following the major roads, due to obstruction by mountainous terrain.
- b) From the maps we can see all three cities mainly expand along major roads,

although Suao, located at the southern tip of the Lanyang Delta surrounded by mountains is restricted in its development by the terrain. Therefore its expansion is along the main roads along the valley.

- c) From Table 3, Luodong and Suao are more inclined to expansion by diffusion, which means their growth is more scattered than that of Yilan. The spread expansion of Suao is much greater. The spread expansion of Yilan and Luodong is equal, while Suao is influenced by resistance from the mountainous surroundings.
- d) Comparing the best coefficient and fit coefficient, the speed of diffusion and spread expansion in Yilan city will be continue to increase. The expansion speed of Luodong will be even faster. On the other hand, Suao will experience almost no change. The value of slope resistance in Suao is decreasing because in past trends, more structures have been built on slopes in the area.
- e) From Figure 1 we can see the population of Yilan city and Luodong has rapidly increased, while that of Suao is growing much more slowly. Urban area change in Yilan, Luodong and Suao between 1964 and 2002 is shown in figure 5. The urban area change has increased rapidly in Yilan and Luodong in proportion to population increase. Between 1974 and 1990 the urban area change in Yilan was much higher than in Luodong, while between 1990 and 1995 both cities increased at a very slow growing rate. From 1995 to 2002 the urban area change in Luodong picked up, equaling the increasing rate of Yilan. Throughout the period covered by the graph, Suao has hardly changed.
- f) The predicted urban area change in Yilan, Luodong and Suao between 2002 and 2030 is shown in Figure 6. If the present trends of urban expansion remain the same, we have predicted the urban growth of the three cities until 2030. We predict Yilan city and Luodong will continue to expand more and more rapidly, while the expansion of Suao will continue to be very slow. The predicted urban area is given in Table 4.
- g) A future study should be conducted in four different metropolitan regions of Taiwan. We will digitize vector data from early base maps and 80s and 90s transportation and building data from remote sensing image classification by using medium and high resolution satellite images, such as SPOT, IKONOS, QUICKBIRD and FORMOSAT-2. This hybrid method of combing remote

sensing and GIS data provides a way to understand and predict the future city development of different metropolitan regions of Taiwan.

References

- Cheng, J. and Masser, I. (2004). *Understanding Spatial and Temporal Processes of Urban Growth: Cellular Automata Modeling*. Environment and Planning B: Planning and Design, Vol. 31, pp. 167-194.
- Clarke, K.C and Gaydos, L.J (1997). *A Self-Modifying Cellular Automaton Model of Historical Urbanization in the San Francisco Bay Area*. Environment and Planning B: Planning and Design, Vol. 24, pp. 247-261.
- Clarke, K.C and 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 Vol. 12, No.7, pp. 699-714.
- Couclelis, H. (1997). *From Cellular Automata to Urban Models: New Principles for Model Development and Implementation*. Environment and Planning B: Planning and Design, Vol. 24, pp.165-174.
- Leao, S., Bishop, I. and Evans, D. (2004). *Simulation Urban Growth in a Developing Nation's Region Using a Cellular Automata-Base Model*. Journal of Urban Planning and Development Vol. 130, No.3, pp.145-158.
- Li, Xia and Yeh, Anthony Gar-On (2000). *Modeling Sustainable Urban Development by the Integration of Constrained Cellular Automata and GIS*. International Journal of Geographical Information Science, Vol. 14, No.2, pp.131-152.
- Silva, E.A and Clarke, K.C (2005). *Complexity, Emergence and Cellular Urban Models: Lessons Learned from Applying Sleuth to Two Portuguese Metropolitan Areas*. European Planning Studies Vol. 13, pp.93-116.
- Weng, Q. (2001). *A Remote Sensing-GIS Evaluation of Urban Expansion and its Impact on Surface Temperature in the Zhujiang Delta, China*. International Journal of Remote Sensing, Vol. 22, No.10, pp.1999-2014.
- White, R., Engelen, G. and Uljee, I. (1997). *The Use of Constrained Cellular Automata for High-Resolution Modeling of Urban Land-Use Dynamics*. Environment and Planning B, Vol. 24, pp.323-343.
- Wu, F. and Webster, C. J (1998). *Simulation of Land Development through the Integration of Cellular Automata and Multi criteria Evaluation*. Environment and Planning B, Vol. 25, pp.103-126.
- Yang, Xiaojun and Lo, C.P (2003). *Modeling Urban Growth and Landscape Changes in the Atlanta Metropolitan Area*. International Journal of Geographical Information Science, Vol.17, No.5, pp.463-488.
- Yeh, Gar-On and Li, Xia (1998). *Sustainable Land Development Model for Rapid Growth Areas Using GIS*. International Journal of Geographical Information Science, Vol.12, No.2, pp.169-189.