Modeling urban growth pattern for sustainable archaeological sites: A case study in Siem Reap, Cambodia

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Abstract: In this paper, the main goal is to understand the relationship between urban growth and physical factors in order to determine the potential area for future urban expansion. A policy is suggested that could effectively sustain the archaeological sites and to balance the land use between urban and non-urban areas in Siem Reap, Cambodia. Remote sensing is used to analyze land use maps of Siem Reap from 1993 to 2011. Results show that urban-built up area increased significantly which causes the forest land to reduce in the Siem Reap archaeological sites. In addition, Geographic Information System (GIS) is used to analyze urban growth in potential suitable sites. Geo-processing and logical functions are applied to detect and quantify the land use changes, especially urban changes. The percentage of urban area in each year is compared with the population density and road buffers by using Pearson correlation. It is shown that the increasing in urban area is related with population density and road network factors.

Key-Words: GIS, land use, urban growth, sustainable, archaeological sites

1 Introduction

There are only few landscapes on the earth which are still in natural state. Over the past 50 years, the world has been altered noticeably by human especially through urbanization, deforestation, and agriculture. The land use and land cover pattern of a region is the result of natural and socio-economic factors and their utilization by human in time. Though conversion of vacant land to agriculture and rate of deforestation vary across the world, the number of inhabitant inside cities has been increased rapidly. Economic and cultural globalization forces are observed as the dominant influence on urban change [1, 2]. Based on the 2005 Revision of World Urbanization Prospects reported by the Department of Economic and Social Affairs' Population Division of the United Nations (UN, 2006), in 1950, only 13% of the world population lived in urban areas; this percentage increased to 29% by 1990, and it reached 49% by 2005. Moreover, it has been projected by United Nation that half of the world population would live in urban area by end of 2008. Furthermore, according to the 2005 final report made by Asian Development Bank (ADB), in 2005 the urban population is expected to grow from 20% of the total population to 35% in 2030. It has been shown in figure that urban population will rise from 2.9 million in 2005 to 8.0 million in 2030, more than doubling the current urban population. Land use in urban areas changes uninterruptedly because of the construction of new buildings, roads, and other human made features. Up-to-date maps and information is very important for urban planners to make and develop the development plan. Meanwhile, Geographic Information System (GIS) integrated with Remote Sensing are very powerful tool to analyze, track the trend of change, and retrieve reliable information. Therefore, the main objective of the work presented in this paper is to explore the urban growth pattern and its relationship with physical factors, in order to identify the suitable areas for urbanization with less harm on archaeological sites.

2 Urban growth analysis

Understanding urban growth and change is critical to city planners and resource managers in these rapidly changing environments [7]. A number of analytical and static urban models have been developed that are based on diverse theories such as urban geometry, size relationship between cities, economic functions and social and ethnic patterns with respect to city structures. A research has been carried out on urban growth modeling by using GIS-based integrated approached in the Charleston region of South Carolina in [3]. An integrated model has been proposed considering the Logistic regression model, Focus group model, and Rule based model. For this model, which developed for Charleston region, 15 independent variables were used to measure physical suitability, accessibility to infrastructure and facilities, market factors, policy constraints. Rule-Based model was developed to further enhance the relative transition probabilities of urban growth for future prediction. The third technique used in this research is focus group mapping. Group of local experts, planners, developers, conservationist, and other relevant communities, who have knowledge and experience of the region and urban growth factors were invited to meetings, and interviewed individually to express their opinion in which direction that urban area is going to expand during next 30 years. Each model was weighted and combined to form integrated model. In [4], a research has been developed on urban growth pattern modeling: a case study of Wuhan city, PR China. In this reason, Jianquan Chen used spatial analysis method to seek and compare determinants of urban growth pattern in the specific period. Exploratory data analysis and spatial logistic regression methods were applied in this study. Exploratory spatial data analysis (ESDA), this technique is operated to detect spatial pattern in dataset, and to develop hypothesis to be tested in spatial logistic regression model. In this research, from the explanatory variables, the factors for suitable urban area are transport and communication include major roads, minor roads, rail lines, which show the direct access to the city centers or sub-centers and industrial centers. A research has been conducted in [5] on application of an integrated system dynamics and cellular automata model for urban growth assessment: a case study of Shanghai, China. In this paper, Ji Han presented an integrated system dynamic and cellular automaton not only in socio-economic driving forces analysis, but also in urban spatial pattern evaluation. Roads network planning plays an important role in directing the development of newly urbanized land. In [6], an urban growth prediction has been proposed from spatial indicators based on multi-temporal images. In this research, a spatial statistical model was used to support decision-making with regard to urban growth predictions in the urban fringe of Beijing, China.

3 Research methodology

This study used GIS and Remote sensing integrated approach for detecting the land use/land cover especially urban growth pattern from 1993 to 2011. The flowchart of research methodology is described below in figure 1.

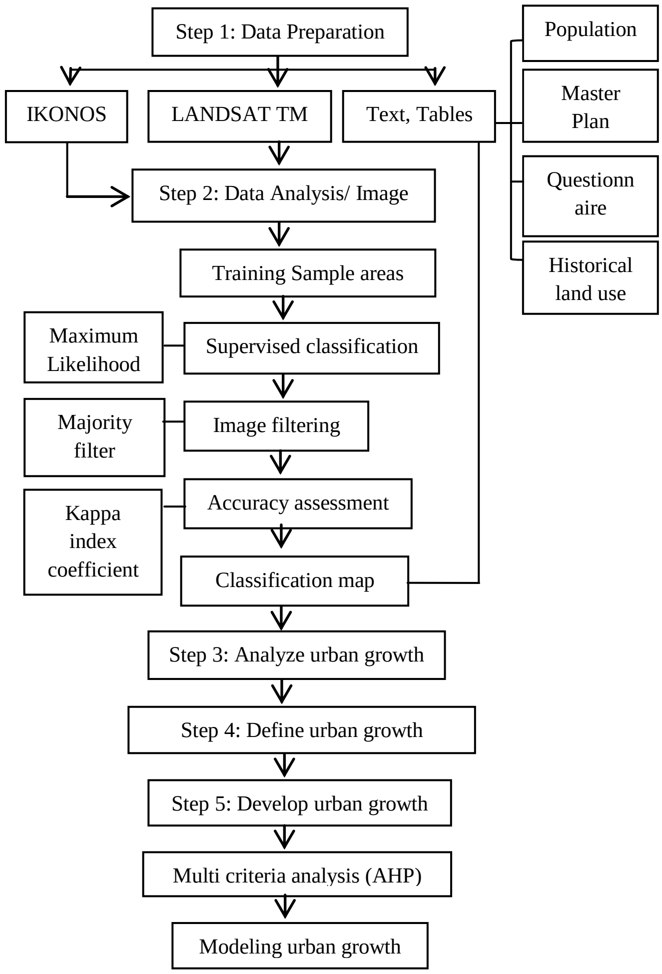

Figure 1: Methodology flowchart

3.1 Data preparation

Urban area used in this research is defined as urban or built up land. Remotely sense data from different years were acquired to obtain land use classification map by years. Landsat TM imageries with 30mx30m resolution were captured from U.S. Geological Survey (USGS) in different time periods. Survey questionnaires forms were prepared during field survey visit. Key experts were the target groups to be interviewed during data collection to identify the urban driving force factors.

3.2 Image analysis

Image classification is performed using remote sensing software, which requires multispectral image having at least two channels. There are two types of image classification, supervised and unsupervised classification. Unsupervised classification is used to cluster pixels in the data set based on statistics without any user-defined training classes. ISODATA unsupervised classification technique (for more information see [8]) is performed to extract the information. The purpose of unsupervised classification is to get additional information for supervised classification. Supervised classification means to determine the decision rule for classification; it required that the operator be familiar with the area of interest (AOI). The operator needs to know where to find the classes of interest in the area covered by the image. After the training sample sets have been defined, classification of the image can be carried out by applying a classification algorithm. The choice of the algorithm depends on the purpose of the classification and the characteristics of the image and training data. The Maximum Likelihood Classifier (for more information see [8]) is very popular and well-known in supervised classification. Maximum likelihood Classification is a statistical decision criterion to assist in the classification of overlapping signatures; pixels are assigned to the class of highest probability. The accuracy assessments of both supervised and unsupervised classification techniques were made through a confusion or error matrix. A confusion matrix (for more information see [8]) contains information about actual and predicted classifications done by classification system. The pixel that has been categorized from the image was compared to the same site in the field.

3.3 Analyze urban growth pattern and factors related to growth

GIS technique was applied to convert from GRID file to Vector. In the meanwhile, Geo-processing and logical function were applied to detect and quantifying the land use change especially urban change. Statistical tabulation of land use change by years has been plotted. Moreover, the factors affected land use change were compared with the growth of urban built up areas in order to detect if there is any relationship among those by using Pearson correlation approach. Pearson correlation was used to measure the degree of relation between two variables (X, Y) which range from -1 to +1. Positive value for correlation reveals a positive relation, means that the big value of X tend to relate with the big value of Y, and the small value of X tend to relate with the small value of Y. Negative value for correlation illustrates an inverse relation, means that the big value of X tend to relate with the small value of Y and vice versa. The correlation is computed as

(1)

Where X, Y are the variables

S_X, S_Y are the standard deviation

In this study, urban driving force factors came from interviewing with key experts, which conducted during field survey.

3.4 Analytic Hierarchy Process (AHP)

Multi criteria approach was used to support in criteria weighting for each urban driving force factors. The influences of urban growth factors are varied. Based on the urban geography in [10], settlement areas have different pattern. For instance, linear settlement is a small to medium size settlement which is formed along the transportation route such as roads, river, and canal. In this case, road is the most important factor affecting urban growth and is given high weight also comparing to other factors. The pairwise comparison method in the context of the Analytic Hierarchy Process (AHP) has been developed (for information see [9]. AHP provides an accurate and efficient methodology to find the relative importance of each of the factors in the hierarchy. By organizing and assessing alternatives against a hierarchy of multifaceted objectives, AHP provides a proven, effective means to deal with complex decision making. It is considered an efficient process to select criteria, define their weights and perform analysis, interviewing participants that have to compare the importance of factors, two at a time.

4 A case study: Siem Reap, Cambodia

With a total land area of 181,035 square kilometers, the Kingdom of Cambodia is the smallest of the former Indochinese countries. It is bounded to the west of and northwest by Thailand, to the north by Laos, to the east and southeast by Vietnam, and to the south by the Gulf of Thailand. Cambodia's geographical position in extreme co-ordinates, North: 10°N/ South: 15°N/ East: 108°/ West: 103°E, which is shown in Fig 2. Siem Reap is one of the ancient cities in Cambodia, which attracted many tourists every year to visit the World Heritage. Angkor Wat temple, located in Siem Reap town has been inscribed in the World Heritage list and the World Heritage in Danger on 14th December 1992. Siem Reap, district of today, includes a large part of Angkor area, the well-known UNESCO-protected world heritage site, which is a symbol of glorious Khmer history and culture.

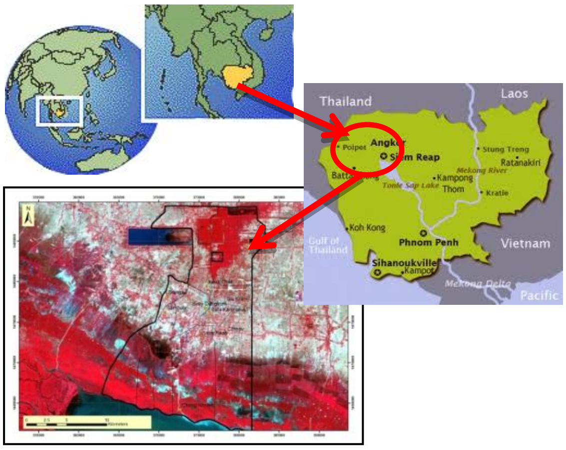

Figure 2: Map of the study area: Siem Reap, Cambodia

4.1 Data acquisition

Satellite images were acquired from Landsat TM 1993, 2003, 2006, and 2011 and IKONOS image 2005 as map base. Ground truth data with the help of Global Positioning System (GPS) was collected during field survey for reference data. Satellite images were used to process land use classification map. Beside satellite imageries, primary data collection was conducted to support the analysis of this research study. In this study, qualitative data have been collected by using interviewing methods with key persons regarding to social and economic issues, which cause urban growth in Siem Reap. Interviewing is a technique, which is primarily used to gain an understanding of the underlying reasons and motivations for people's attitudes, preferences or behavior

4.2 Land use change detection map

Land use map by years have been generated from supervised classification method as shown in Fig. 3, 4, 5, and 6. It revealed that the total urban area has increased significantly from 1965.72 ha in 1993 to 3980.79 ha in 2011. This can be concluded that the urban area will expand in the future. However, the agriculture land increased sharply from 1993 to 2006 and steadily decreased in 2011. The increase of the number of visitor in Siem Reap has led people to abandon cultivated land, preferring to run a business or find a job in urban areas.

4.3 Urban growth pattern and the factors related to urban growth

Based on literature review [3, 4, 5, 6], distance to roads, distance to sewer lines, distance to water line, distance to existing urban area, transportation and communication, social and economic factors such as land value, population, employment opportunity were identified as the main urban growth factors.

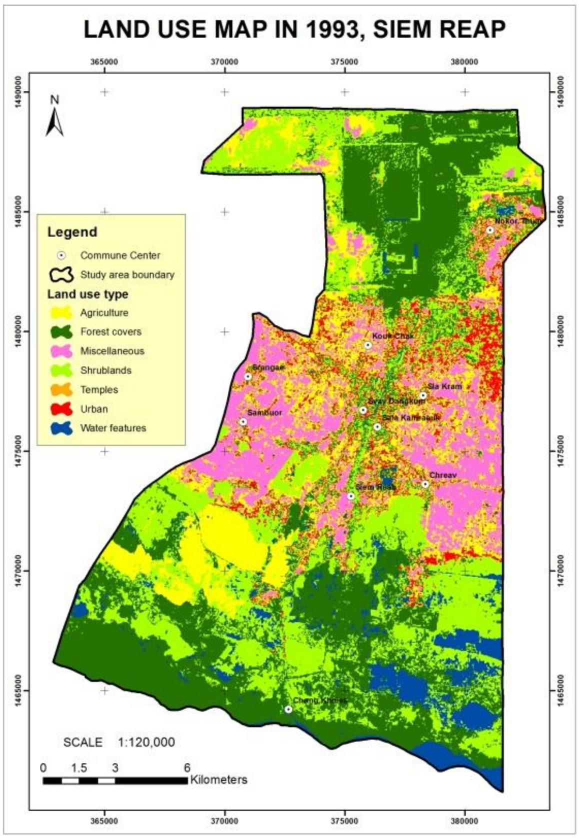

Figure 3: Land use map in 1993, Siem Reap, Cambodia

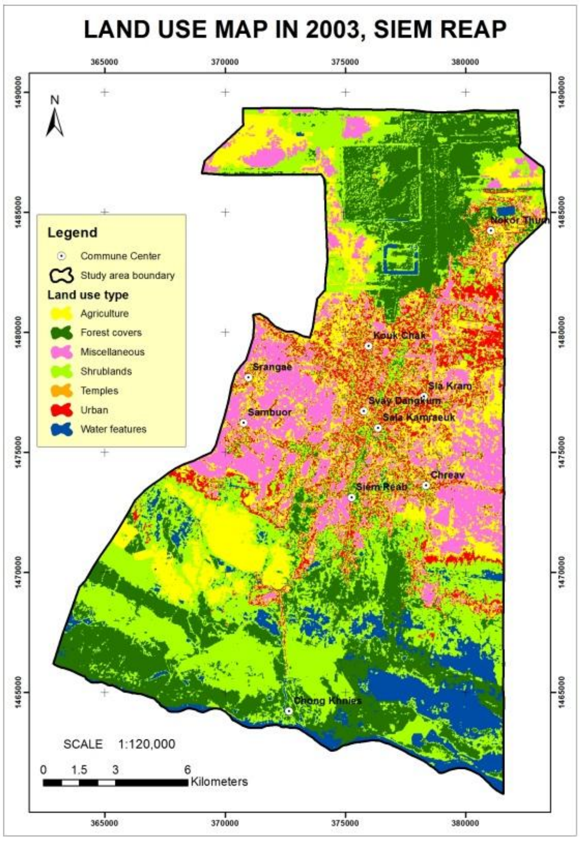

Figure 4: Land use map in 2003, Siem Reap, Cambodia

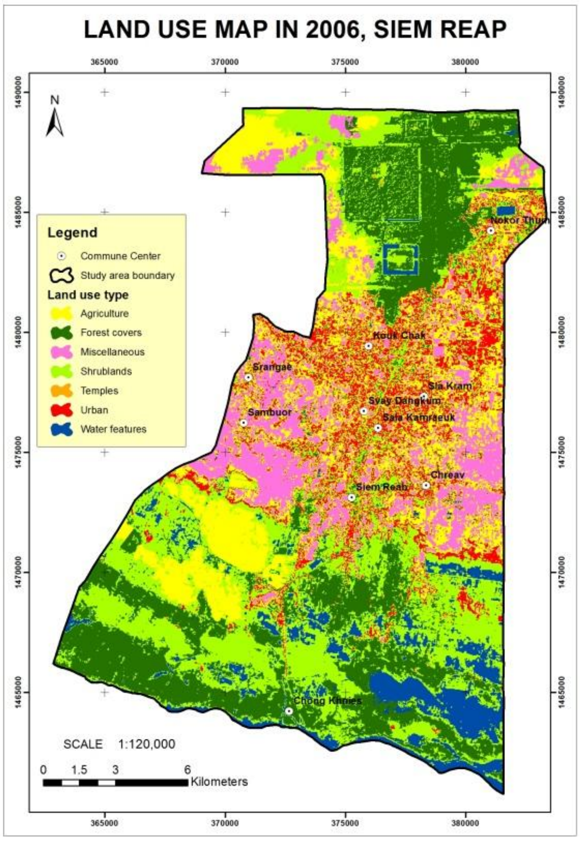

Figure 5: Land use map in 2006, Siem Reap, Cambodia

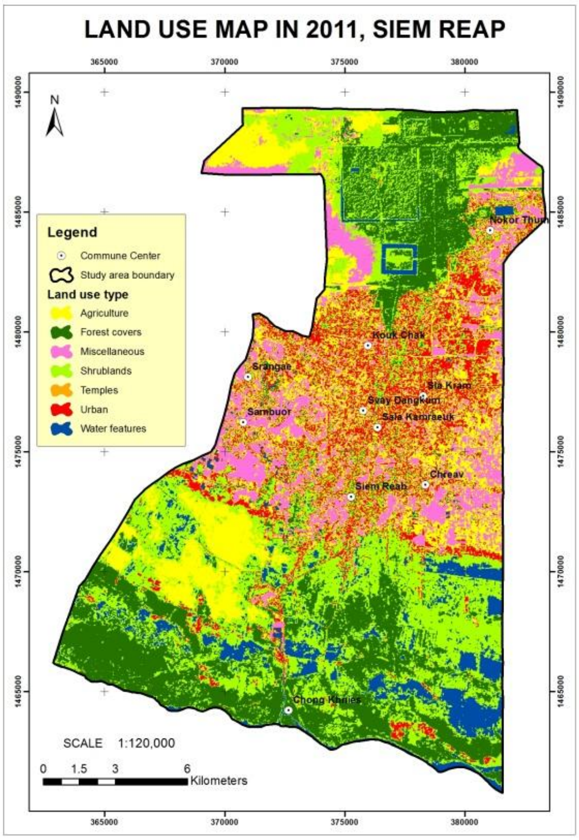

Figure 6: Land use map in 2011, Siem Reap, Cambodia

Survey-questionnaires involving key experts in Siem Reap were applied: analyzing the answers, population density and distance to roads were identified as the major determinant for urban driving force in Siem Reap.

4.3.1 Relationship between distance to roads and urban growth

The buffers from the road line were created with an increment 100 meters from 0 meter to 2000 meters. The percentage of additional urban area in buffer *n* was used to calculate the relationship by using the. Pearson correlation as presented in table 1 below.

Table 1: Pearson correlation between distance to road and urban growth in buffer *n*

Years	**1993**	**2003**	**2006**	**2011**	**Average**
Roads	-0.82	-0.78	-0.80	-0.81	-0.80

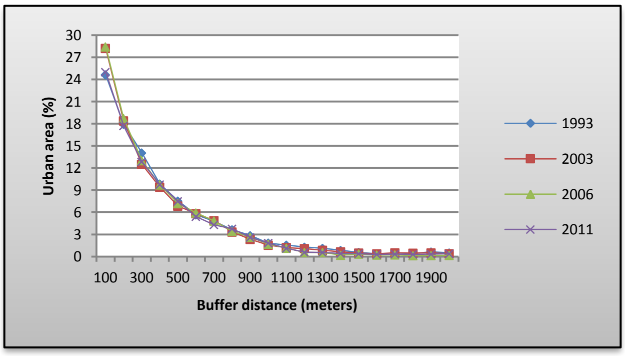

Figure 7: Graph of percentage of additional urban area with buffer *n*

Pearson correlation was used to calculate the relation between roads and urban growth. The value shows in Table 1 illustrates that the relationship between roads and urban is strong negative correlation which equal to -0.8 in average. Therefore, the road has high effect on urban growth. The location of new roads shall be selected carefully on the area of preservation archaeological zone.

4.3.2 Relationship between population density and urban growth

The percentage of urban area in each year is compared with the population density by using Pearson correlation as shown in table 2.

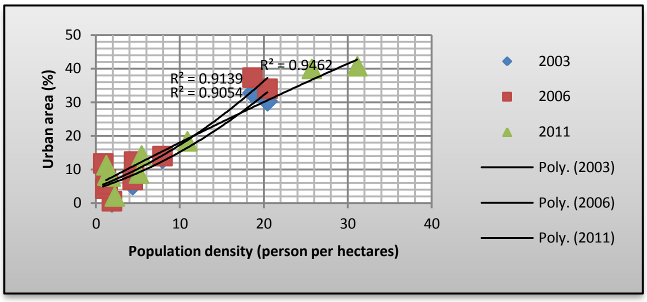

Figure 6: Percentage of urban area and population density in each years

Table 2: Pearson correlation between distance to road and urban growth in buffer *n*

Years	**2003**	**2006**	**2011**	**Average**
Population	0.94	0.95	0.97	0.95

Pearson correlation was used to calculate the relation between population density and urban growth. The value shows in Table 2 reveals that the relationship between population density and urban is strong positive correlation which equal to 0.95 in average. Therefore, population density has high effect on urban growth.

5 Conclusion

Siem Reap is the major tourist hub in Cambodia, well-known by its world heritage. The impacts of landscape change on the environment due to urbanization became a true concern. This research aims to understand the relationship between urban growth and physical factors, in order to identify suitable areas for urban expansion by using multi-criteria analysis. Results showed that there are two majors urban driving force in Siem Reap, which are the distance to roads and population density. The additional urban area grew more in roads buffer from 0m to 100m, while it dropped steadily from 100m to 2000m. Meanwhile, population density showed that it has a high effect on urban area expansion. The next step of this work will be finding suitable sites for urban growth in Siem Reap. AHP approach will apply to define the hierarchy of the urban driving force factors. Lastly, opinions from key experts will use to assign the scale for pairwise comparisons. Then, using a GIS toolset, this defined hierarchy will be integrated in a process for mapping potential urban expansion that takes into account the preservation of archeological sites. The model is intended to provide a vision of the future, working as a tool to help increase environmental awareness. Future developments should conclude with the proposal of policies to maintain sustainable balance between urban and non-urban area.

References:

[1] Cohen, B., Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts, *World Development*, Vol. 32, No. 1, 2004, pp. 23-51.

[2] Cohen, B., Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability, *Technology in Society*, Vol. 28, Issues 1-2, January-April 2006, pp. 63-80.

[3] Allen, J. and K. Lu., Modeling and prediction of future urban growth in the Charleston region of South Carolina: a GIS-based integrated approach. *Conservation Ecology* Vol. 8, Issue. 2, 2003, [online] http://www.consecol.org/vol8/iss2/art2

[4] Cheng, J.; Masser, I., Urban growth pattern modeling: A case study of Wuhan city, PR China, *Landscape and Urban Planning*, Vol. 62, Issue: 4, 2003, pp. 199-217.

[5] Han, J.; Hayashi, Y.; Cao, X., Imura, H., Application of an integrated system dynamics and cellular automata model for urban growth assessment: A case study of Shanghai, China , *Landscape and Urban Planning*, Vol. 91, Issue. 3, 2009, pp. 133-141.

[6] Huiping Lui, Qiming Zhou, 2005. Developing urban growth predictions from spatial indicators based on multi-temporal images: Computers, *Environment and Urban Systems*, Vol. 29, Issue. 5, September 2005, pp. 580-594.

[7] Knox, P. L., *The restless urban landscape. Englewood Cliffs*, NJ: Prentice-Hall, 1993.

[8] Lillesand, T. M.; Kiefer, R. W.; Chipman, J. W., *Remote Sensing and Image Interpretation (5th ed.)*. New York: John Wiley and Sons, 2004.

[9] Saaty, T. L., *The analytic hierarchy process*, Mc Graw-Hill, New York, 1980.

[10] Pacione, M., *Urban Geography- A global perspective*. London and New York: Routledge, 2009.