A proposed methodology for understanding urban growth pattern: 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 methodology is suggested for understanding urban growth pattern in Siem Reap which could effectively sustain archaeological sites and to balance the land use between urban and non-urban areas in Siem Reap, Cambodia. Remote sensing technique 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 steadily from 1993 to 2003 in the Siem Reap archaeological sites. In addition, Geographic Information System (GIS) is applied to analyze urban growth pattern. Geo-processing and logical functions are applied to detect and quantify the land use changes, especially urban changes. Two main factors are used to analyze the urban driving growth in Siem Reap, which are distance to road networks and population density. Pearson correlation statistics is applied to justify the relationship between the factors and urban area growth.

Key-Words: GIS, land use, urban growth pattern, remote sensing

1 Introduction

There are few landscapes on earth which are still in a natural state. Over the past 50 years, the world has altered noticeably especially through the impact of 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 use by humans over time. Though conversion of vacant land to agriculture and rate of deforestation vary across the world, the number of inhabitants inside cities has increased rapidly. Economic and cultural globalization forces are observed as the dominant influence on urban change [1, 2]. Based on the 2009 Revision of World Urbanization Prospects reported by the Department of Economic and Social Affairs' Population Division of the United Nations (UN, 2009), in 1950, only 28.8% of the world population lived in urban areas; this percentage increased to 42.6% by 1990, and it reached 50.5% by 2010. Moreover, it has been projected that the urban population is expected to grow from 50.5% in 2010 to 59% in 2030. It has been shown that urban population will rise from 3.4 million in 2010 to 4.8 million in 2030 [3]. 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 are very important for urban planners to make and develop the development plan. Meanwhile, Geographic Information System (GIS) integrated with Remote Sensing are a 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, and to determine the suitable locations for less harmful urbanization 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 [4]. A number of analytical and static urban models has been developed, based on diverse theories such as urban geometry, size relationship between cities, economic functions and social and ethnic patterns with respect to city structures. In 2003, Allen and Lu presented their study on urban growth modeling, using GIS-based integrated approaches in the Charleston region of South Carolina [5]. An integrated model has been proposed considering the Logistic regression model, Focus group model, and Rule based model. For this model, which was developed for the Charleston region, 15 independent variables were used to measure physical suitability, accessibility to infrastructure and facilities, market factors and policy constraints. A 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. A group of local experts, planners, developers, conservationists, 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 an integrated model. In 2002, Jianquan et al., proposed a research on urban growth pattern modeling: a case study of Wuhan city, PR China [6]. A spatial analysis method was applied to seek and compare determinants of urban growth pattern in the specific period. Exploratory data analysis and spatial logistic regression methods were also operated in this study to detect spatial pattern in the dataset, and to develop hypothesis to be tested in a spatial logistic regression model. In this research, from the explanatory variables, the factors for suitable urban area were transport and communication including major roads, minor roads, rail lines, which showed the direct access to the city centers or sub-centers and industrial centers. In 2009, Jihan et al., conducted a research on application of an integrated system dynamics and cellular automata model for urban growth assessment: a case study of Shanghai, China [7]. An integrated dynamic system with cellular automata (CA) approach was conducted to analyze not only the socio-economic driving forces, but also the urban spatial pattern evaluation. It has been found that roads network planning plays an important role in directing the development of newly urbanized land. In 2005, Huiping et al., proposed the study on developing urban growth prediction from spatial indicators based on multi-temporal images [8]. An integration of remote sensing and GIS technique were applied to detect the spatial distribution of land use and spatio-temporal pattern over the years. Moreover, a multivariate model was adopted to determine the relationship between urban expansion and factors related to growth. Finally, land use/land cover pattern were integrated in a multivariate spatial model to estimate the spatial distribution of future urban expansion.

3 Research methodology

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

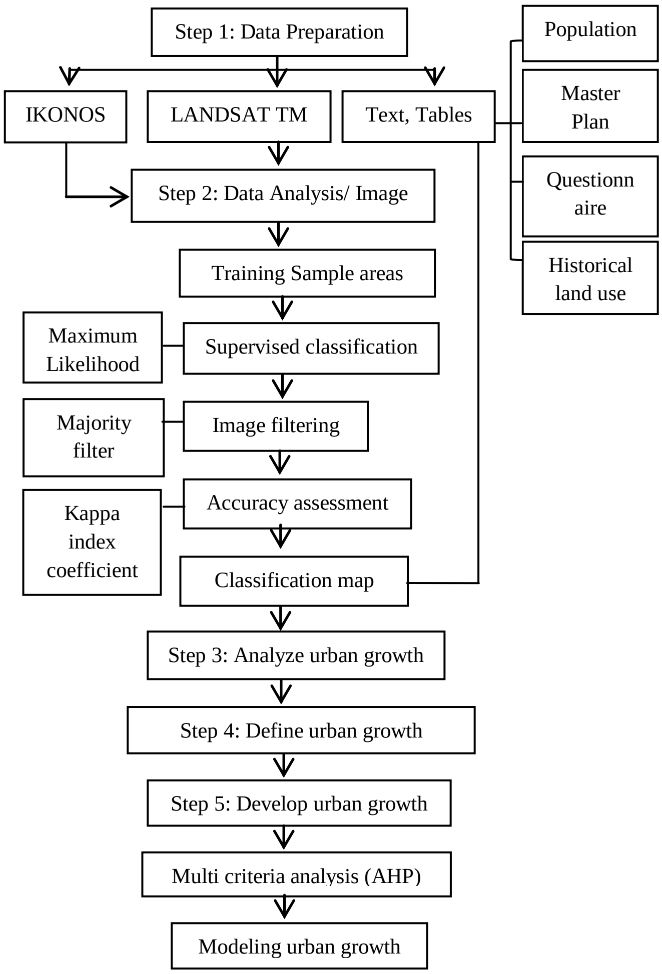

Figure 1: Methodology flowchart

3.1 Data preparation

The urban area used in this research is defined as urban or built up land. Remotely sensed data from different years were acquired to obtain the land use classification map per year. Landsat TM imageries with 30mx30m resolution were captured from U.S. Geological Survey (USGS) in different time periods. Survey questionnaire forms were prepared during field survey visits. 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 [9]) is

ISBN: 978-1-61804-060-2

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 requires that the operator is 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 [9]) 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 [9]) contains information about actual and predicted classifications made by the classification system. The pixel that has been categorized from the image was compared to the same site in the field.

3.3 Analysis of urban growth pattern and factors related to growth

GIS technique was applied to convert from GRID file to Vector. Meanwhile, geo-processing and logical function were applied to detect and quantify the land use change especially urban change. Statistical tabulation of land use change per year 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, 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. A positive value for the correlation reveals a positive relation, meaning that a high value of X tends to relate with a high value of Y, and a low value of X tends to relate with a low value of Y. A negative value for the correlation illustrates an inverse relation, meaning that a high value of X tends to relate with a low value of Y and vice versa. The correlation is computed as

$$r = \frac{\sum_{i-1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{(n-1)S_X S_Y} \quad (1)$$

Where X, Y are the variables

S_X, S_Y are the standard deviation

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

3.4 Analytic Hierarchy Process (AHP)

A multi-criteria approach was used to support in criteria weighting for each urban driving force factors. The influence of the urban growth factors is 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 a transportation route such as a road, river, and canal. In this case, a road is the most important factor affecting urban growth and thus it is given higher weight in comparison with other factors. The pairwise comparison method in the context of the Analytic Hierarchy Process (AHP) has been developed (for information see [11]). 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 weights and perform analyses, by 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 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 is, North: 10°N/ South: 15°N/ East: 108°/ West: 103°E, as shown in Figure 2. Siem Reap is one of the ancient cities in Cambodia, which attracts many tourists every year to visit the World Heritage site. 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, a district, 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.

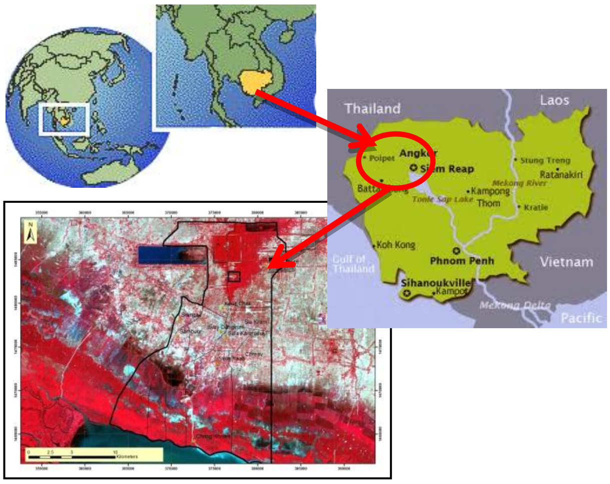

Figure 2: Map of the study area

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 interview methods with key persons regarding 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 per years have been generated from the supervised classification method as shown in Fig. 3, 4, 5, and 6. It revealed that the total urban area has increased significantly from 19.65km^2 in 1993 to 39.80km^2 in 2011. Moreover, as shown in land use map from 1993 to 2003, the forest area has declined considerately from 108.20 km^2 to 80.04 km^2, prompted by an increase of human demand for housing and agriculture, logging included legal and illegal. However, since the creation of APSARA (Authority for the Protection and Management of Angkor and the Region of Siem Reap) in 1995, reforestation has been applied mostly near the archaeological zone.

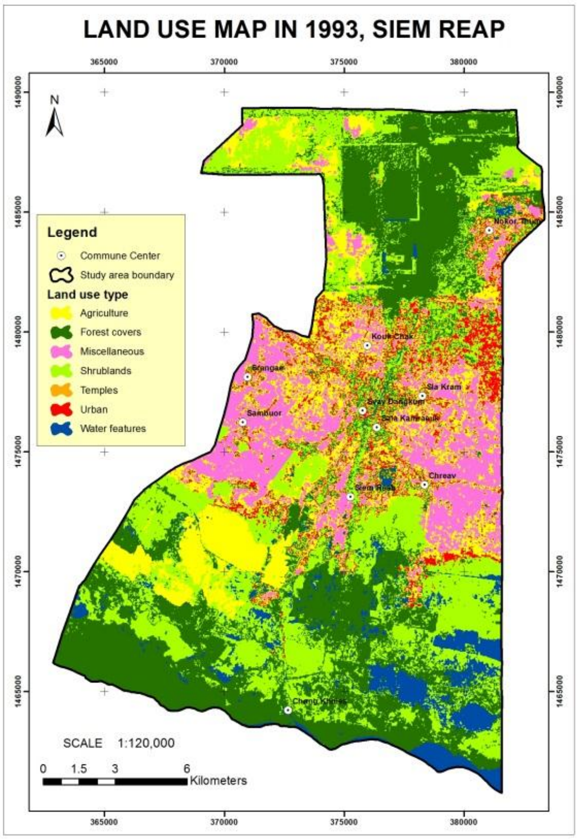

Figure 3: Siem Reap - Land use map in 1993

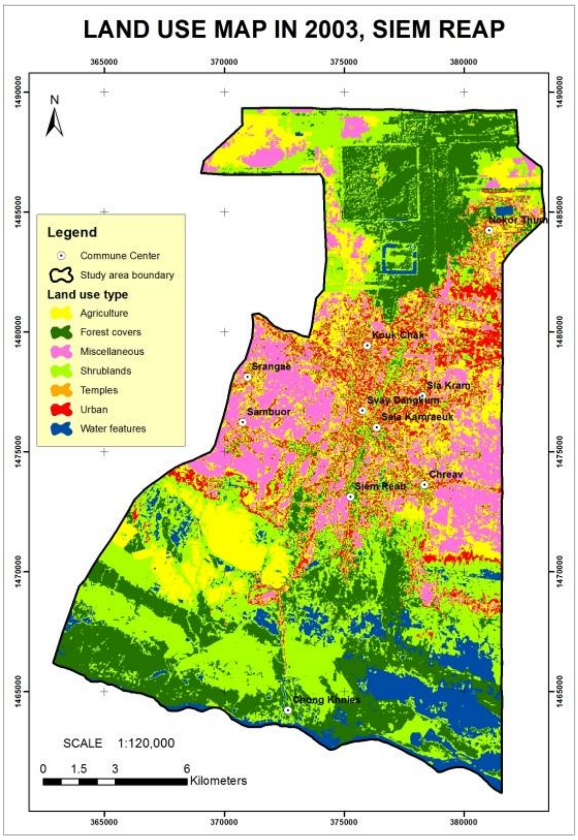

Figure 4: Siem Reap - Land use map in 2003

ISBN: 978-1-61804-060-2

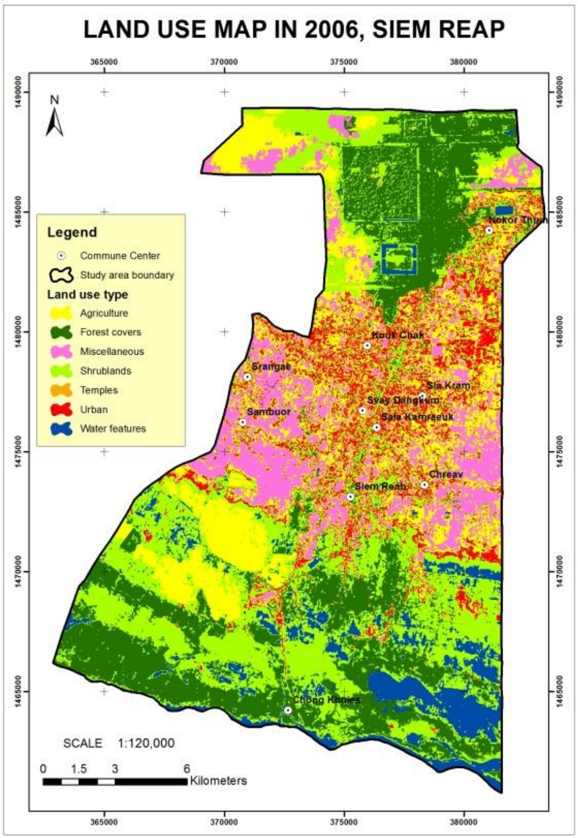

Figure 5: Siem Reap - Land use map in 2006

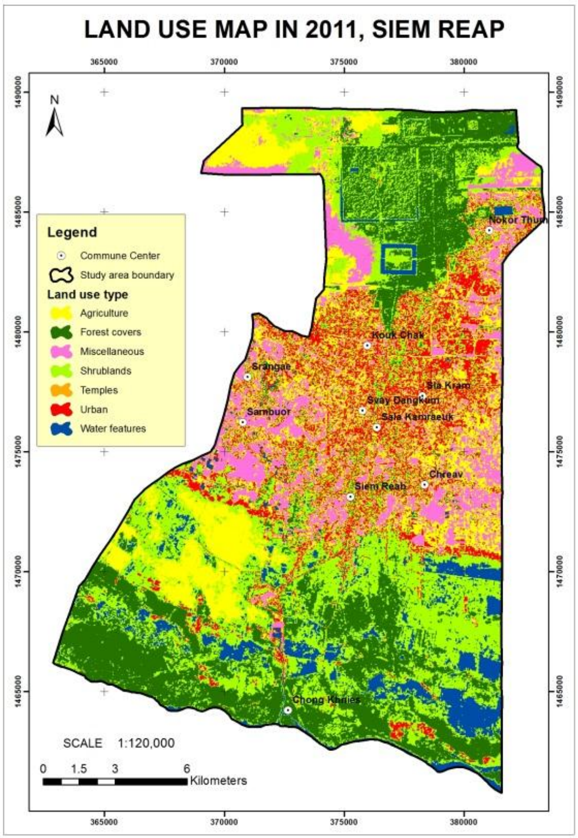

Figure 6: Siem Reap - Land use map in 2011

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 areas is a strong negative correlation, equal to -0.8 in average. Therefore, the roads have high effect on urban growth. The location of new roads shall be selected carefully on the area of preservation of the archaeological zone.

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

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

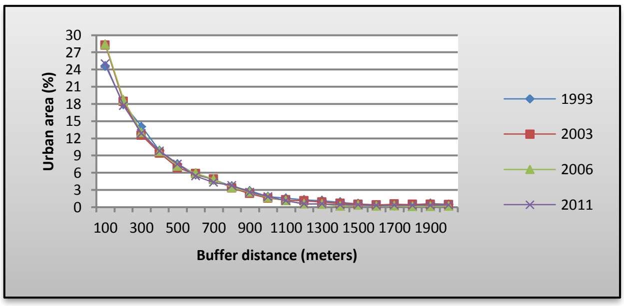

Figure 7: Graph of percentage of additional urban area with buffer *n*

4.3.2 Relationship between population density and urban growth

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

Table 2: Pearson correlation between population density and urban growth in buffer *n*

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

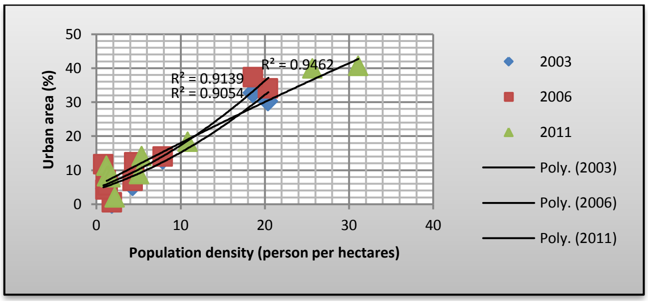

Figure 8: Percentage of urban area and population density in each years

The urban area per year was extracted from land use maps and was compared to population density. Pearson correlation was then used to calculate the relation between population density and urban growth. The values shown in Table 2 reveal that the

ISBN: 978-1-61804-060-2

relationship between population density and urban is a strong positive correlation which equals to 0.95 in average. Therefore, population density has high effect on urban growth. It means that a area which has high population density is more susceptible to be converted into an urban built up area than an area which has low population density.

5 Conclusions

Siem Reap is the major tourist hub in Cambodia, well-known for the world heritage site. Landscape changes due to urbanization are significant. This paper exposed the relationship between urban growth and physical factors. From interviews to key experts during field visits, it was concluded that two factors are the major urban driving force in Siem Reap: the distance to roads and the population density. Using remote sensing data and comparing land use evolution, it was showed that the urban area grew more in roads buffer from 0m to 100m, while it dropped steadily from 100m to 2000m. The next step of this work will be finding suitable sites for urban growth in Siem Reap. AHP approach will be applied to define the hierarchy of the urban driving force factors. Lastly, opinions from key experts will be used to assign weights through the 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 for the future, working as a tool to help increase environmental awareness. Future development should conclude with the proposal of policies to maintain a sustainable balance between urban and non-urban areas.

References:

[1] Cohen, B., Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts, *World Development*, 32(1), pp. 23-51, 2004.

[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, pp. 63-80, 2006

[3] United Nations, *World Urbanization Prospects: The 2009 Revision Population Database 2009*, http://esa.un.org/wup2009/unup, 2009.

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

[5] 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*, 8(2), 2003. [online] http://www.consecol.org/vol8/iss2/art2

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

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

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

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

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

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