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Research Paper

Urban growth assessment and prediction using RS, GIS and SLEUTH model for a heterogeneous urban fringe

Mahesh Kumar Jat *, Mahender Choudhary, Ankita Saxena

Civil Engineering Department, Malaviya National Institute of Technology Jaipur, Jaipur 302017, India

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ABSTRACT

Urban growth monitoring and assessment are essential for the sustainable natural resources planning & optimum utilization and reducing the risk of problems arising from unplanned urban growth like pollution, urban heat island and ecological disturbances. Cellular Automata (CA) based modelling techniques have become popular in recent past for simulating the urban growth. Present study is aimed to evaluate the performance of the CA based SLEUTH model in simulating the urban growth of a complex and relatively more heterogeneous urban area, Ajmer city of Rajasthan (India) which is quite different as compared to areas where SLEUTH has been tested in developed countries. Seven multispectral satellite imageries spanning over 21 years have been processed and used for SLEUTH parameterisation. Results of urban growth predicted by SLEUTH has been compared with other methods of land use/land cover extraction. The study has been proved to be successful in giving significant insight into issues contributing uncertainties in forecasting of urban growth of heterogeneous urban areas.

1. Introduction

Economic development and population growth have triggered rapid changes to earth land use/land cover as a result of urbanization & industrialization in last two centuries and there is every indication that the pace of these changes will accelerate in the future. Urban growth is the expansion of city area with respect to the increase in number and size of the settlement. Urban expansion chiefly depends upon the human desires for their betterment, need of better livelihood, facilities and employment (Brueckner and Helsley, 2011). Unplanned growth is one of the major factors responsible for many problems like urban heat islands, pollution, climate change, over-exploitation of natural resources and inadequate infrastructure facilities leading to unsustainable developmental situation. Understanding of urban dynamics is difficult for more heterogeneous urban areas as compared to relatively less heterogeneous urban areas. Heterogeneity is associated with different form of development, land use planning, constructions using different type of building & roofing materials, size of built-up units, cultural issues, human behavioural differences and their distribution. Urban areas are comparatively more heterogeneous in developing countries and their assessment, monitoring and prediction is difficult (Sakieh et al., 2015). The lack of knowledge of urban dynamics in developing countries attributed to, poor land use planning, pathetic resource allocation, wretched policy making, and despicable budget allocation (Xian et al., 2005).

In early days, cadastral maps (scale, usually 1: 4000) were utilized in mapping land use/land cover and to detect their changes. From the 20th century onwards land use mapping was replaced by preparation of land use/land cover maps using aerial photographs, which have later replaced by multispectral satellite images. In recent past different type of digital image processing and other mathematical techniques have been utilized for the assessment of urban growth through preparation of land use/ land cover maps using different type of remote sensing data products. Spectral methods, pixel to pixel classification of satellite imageries using supervised classification was in patronage, though, supervised classification has its limitation of overlapping or very similar signatures of different land use classes. For the enhancement of digital image quality, various methods have been used like image differencing, image rationing, differencing of NDVI images and the combined effect of both (photo & digital) type of image products offered better visibility and feature extraction. However, no single image enhancement technique is sufficient for mapping all

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* Corresponding author.
E-mail addresses: mahesh.mnit@gmail.com (M.K. Jat), mahender.choudhary@gmail.com (M. Choudhary), ankita.saxena03@yahoo.in (A. Saxena).

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the land use classes and for correct assessment of urban growth (Prakash and Gupta, 1998). Also, spectral information based methods lacked in capturing urban structures of concrete, asphalt and various kind of roof top materials. Rather doing pixel to pixel image analysis, texture based classification methods and spectral-structural image differencing methods improved the accuracy of urban change analysis (Zhang et al., 2002; El-Asmar et al., 2013). Many land use/ land cover change detection methods were also developed for monitoring landscape change and urban growth in recent past. Efforts have also made to extract correct land use/ land cover and urban growth through analysis of data from different sources in GIS. Level of uncertainties in the results from available methods of land use extraction depends on a variety of issues like resolution of data, radiometric quality of data, level of heterogeneity at a particular place and local climatic characteristics. Therefore, correct mapping (with good accuracy) and land use/ land cover extraction from remote sensing images using different digital image processing methods is still a challenge for complex and heterogeneous areas like urban fringes in developing countries (Jat et al., 2008).

In recent past, new methods of urban growth assessment and prediction have been reported in the literature which include landscape metrics, knowledge based expert systems, agent based modelling, Cellular Automata based algorithms, artificial intelligence and machine learning based techniques. Use of landscape metrics like Number of patches (NP), the Mean patch size (MPS), the Landscape shape index (LSI), Shannon's Diversity index (SHDI), the Mean patch fractal dimension (MPFD) and the Total edge contrast index (TECI) have been used to understand urban growth phenomenon in many studies (Bhatta et al., 2010; Jat et al., 2008; Petit and Lambin, 2001). Landscape metrics are algorithms that quantify specific spatial characteristics of patches, classes of patches, or entire landscape (Butt et al., 2015; Gustafson, 1998; McGarigal & Marks, 1995; Rawat et al., 2013). However, landscape metrics are lacking in quantification of urban growth and its prediction.

In recent past, various models have been reported in the literature which have been used for assessment and prediction of urban growth like statistical models, GIS-based models, cellular automata-based models, agent-based models, rule based models, artificial intelligence based modelling and hybrid models. Few models have been used for the monitoring and assessment of growth and some of them used for growth predictions (Batty, 2001; Verburg et al., 2004; Silva and Wu, 2012).

Spatial Interaction models takes into account the human environment interactions in the form of growth influencing variables. But due to subjective weighting process, fragmented growth cannot be estimated through such models (Fang et al., 2005). Linear or Logistic regression based models are an enhanced approach in spatial modelling which examines the relationships between urban land uses and independent variables. Weighted regression tackle urban dynamics by calculating regression coefficient of spatial weights. Such models lack in calculating fragmented and heterogeneous urban growth due to its dependability on spatial weights. Also, linear and logistic regressions do not offer high modelling capabilities and they fail to capture non-linearity in spatial growth (Hu and Lo, 2007). For enhancing the performance of logistic regression model another model came into existence for example rule based model. As, logistic model rely on the empirical data like other models so, there were no scope of reflecting new growth policies into the scenario. Moreover, rule based models provide higher accuracy as compared to logistic regression modelling. However, implementing complex land use change behaviour in the form of rules did not imply its suitability for heterogeneous urban areas (Thapa and Murayama, 2010). Another modelling techniques is Agent based modelling, which have been used for modelling and prediction of urban growth. It follows a framework in which simulation of urban dynamics is done by the interaction among mobile agents. Also, growth influencing variables like land prices, traffic problem, and landscape attractiveness were included into the framework. In spite of the less computational complexity, initial conditions and interaction rules of agents lead to high uncertainties in the growth simulation results (Matthews et al., 2007). Another technique i.e., Fractal Based Modelling was developed to consider spatio-temporal patterns of urban change. But, due to differences in fractal dimension measurements of the same object using different techniques and sharing the same fractal dimension for different morphological characteristics of objects may not offer reliable results (Weng, 2001; Wu et al., 2009; Dimitrios, 2012). Also, it has limited capability to include the spatial heterogeneity in the modelling process (Triantakonstantis et al., 2013). In recent years, artificial intelligence techniques based urban growth modelling approach have been reported in the literature. Artificial neural network (ANN) was used for the forecasting of urban growth in few studies. Despite the fact of including spatial heterogeneity into the model, it lacked in modelling accuracy due to its tendency to overfit the data (Li and Yeh, 2002). Moreover, ANNs are unable to explicitly identify the contribution of each variable and it encompasses black-box behaviour which limits understanding of urban evolution, and noise tolerance, especially for small sample sizes (Guan et al., 2005). Cellular Automata (CA) based techniques and methods are another widely used approaches for urban growth assessment and forecasting (Candau, 2000).

The Cellular Automata (CA) based SLEUTH model (Silva and Clarke, 2002; Dietzel and Clarke, 2006; Onsted and Clarke, 2012) has been used extensively for the simulation and modelling of urban growth, especially in developed countries. The very first reported application of SLEUTH model was for San Francisco Bay area (Clarke and Gaydos, 1998) and later SLEUTH has been used for the assessment and prediction of urban growth for many other urban areas in different countries most of the developed one. The SLEUTH was tested for different areas with different constraints and growth scenarios for understanding the behaviour and complexity of urban growth phenomenon (Al-shalabi et al., 2013; Herold et al., 2003; Jantz et al., 2004; Oguz et al., 2007). In previous studies, it has been noticed that SLEUTH model is computationally inefficient, sensitive to spatial scale and not able to capture the fragmented urban growth (Silva and Clarke, 2002).

In recent past, improvements have been done in SLEUTH model for making it computationally efficient and for improving accuracy (Chaudhuri and Clarke, 2013). Parallel raster processing (pSLEUTH) has been proposed in SLEUTH for reducing the time constraint in the calibration of model by incorporating decomposition algorithms like QTB (Guan and Clarke, 2010). Efforts have been made to integrated GIS and artificial intelligence (AI) techniques like ANN with cellular automata for minimizing the complexity of transition rules by providing linking among automatic transient neurons and parameter values generated automatically, which was rather difficult in traditional model (Guan et al., 2005; Li and Yeh, 2002; Pijanowski et al., 2002). Additionally, for testing the suitability of the model at fine resolution, SLEUTH model was calibrated for multi-resolution satellite images. Model is very sensitive to the resolution of input land use land cover maps generally prepared from satellite data. Model has performed better in growth simulation with fine resolution data, however, at finer resolutions, it becomes computationally inefficient (Dietzel and Clarke, 2007). Resolution of the input data should be decided based on the average size of housing unit, which is very different from place to place. Form of the development is also very different in different parts of the world. The SLEUTH model has been implemented and found to be satisfactory in simulating the urban growth for the urban areas of developed countries which are less heterogeneous, well planned