LAND USE/ LAND COVER CHANGE MODELLING: ISSUES AND CHALLENGES

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ABSTRACT

Land use change modelling are the tools to support timely and effective monitoring of natural resources through spatio-temporal land use/ land cover (LULC) change detection which can help decision makers for optimum resources planning and utilisation for sustainable rural development. Number of models and approaches have been developed in recent past to analyse land use/land cover change considering different type of data/variables at different levels of complexity and resolution. Such different methods/ models have their own limitations, advantages and suitability in a particular condition. There is no agreement among research community about suitability and effectiveness of a particular method. Present study aims to present a comparative study of popularly used LULC change detection models and techniques. Different models and techniques are compared in terms of level of complexity, considered explanatory variables, spatial extent, temporal dynamism,predictability and level of spatial interaction. For each category, a thorough review of models and approaches is presented which helps in understanding the operational concepts and utility of models/ approaches.

Keywords: Geo-spatial, LULC Change, Modelling, Prediction, Rural Development.

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Introduction

Rural development requires effective monitoring and inventory of natural resources like land, vegetation, forest, water, agriculture, etc., for their optimum planning and utilisation. Land use/ land cover (LULC) change is one of the innovative techniques for natural resources inventory, monitoring and management. Development leads to landscape disturbances, and alteration in LULC and natural resources. Global earth system is bound to remain balanced without which it may produce some irreversible impacts on climate, ecosystem, agriculture system, biodiversity and environment (Jetz et al., 2007; Akin et al., 2014). Therefore, for sustainable development, feild data collection, spatial and temporal monitoring, LULC change detection, methods and models are effective tools. Over the last few decades, a range of LULC change models and approaches have been developed to accurately assess land transformation and functioning of earth system (Agarwal et al., 2002; Jat et al., 2008; Saxena et al., 2016). Land use change modelling, especially if performed in an integrated, multi-scale, dynamism and spatially explicit manner, can be proved as an essential component for land use change forecasting (Aspinall, 2004). An accurate forecasting may enhance the understanding of LULC change processes, driving factors and also can project alternative land use scenarios which may lead to the goal of sustainability. Models have the capability of representing a complex LULC system in an efficient way by incorporating multi-variates.

It also offers the geographical sensitivity and spatial suitability into the model which are utmost important for analysing LULC change for a region (Batty, 2005; Jat et al., 2017). However, each modelling approach may not give accurate meassures because of uncertainity associated with few elements. Though, each has its pros and cons and an inappropriate one in some conditions may be well suited for different scenarios. Due to the advancement in information and communication technology like Geographic Information System (GIS) and remote sensing now, we have advanced modelling approaches which have not been thoroughly compared and evaluated so far (Agarwal et al., 2002; Baker, 1989). Hence, if becaomes still challenge ot identify best suitable model based on accuracy of simulation and spatial and temporal resolutions (Parker et al., 2003; Jat et al., 2008). Present study includes traditional and recently developed modelling approaches to better know the LULC processes, drivers/ explanatory variables and the depth of modelling approaches in terms of modelling complexity, advantages and shortcomings. The main objectives of present study are as summarised below:

1.   To understand the LULC change processes.

2.   Study the importance of LULC explanatory variables.

3.   Different modelling approaches, evaluation on the ground of key measures, issues and challenges.

LULC Change Processes

LULC change can be understood as when dense vegetative regions are no longer in its natural state and used for cultivation, built-up activities and some other means (Lambin et al., 2000). Likewise, other natural land features transformation takes place. However, for fulfilling infrastructure and development demand it is also needed to allow land transformation but not at the cost of over-exploitation of resources that may lead to anunsustainable developmental situation. To maintain the ecological footprint it is necessary to understand the LULC change processes (Geist et al., 2002). It has been observed in various studies that most of the land features are greatly transformed into urban forms and it is synonymous to the built-up land which includes commercial, residential and industrial land uses. So, in the present study also, mere focus has been given to urban transformation. In a digital world of land use modelling, land is portrayed over a multi-dimensional array and by dealing with each pixel which represent a land cover class during modeling process. The nearby land features of urban surroundings will be more prone to get urbanised as it is a human tendency to build around people-surrounded area. To support increased demand of newly grown urban areas for facilitating conspicuous services like sewer, water, electricity, roads and other resources, land will be transformed (Batty and Xie, 1994). It will derive or promote further LULC change along transportation network and at shorter radii to these facilities and this land use change propagates spatially and temporally.

Important LULC Change Drivers and its Modelling

LULC change and urban growth is a function of different explanatory variables such as neighbourhood, proximity, demographic, socio-economic, institutional, suitability, bio-physical and restrictive variables. Neighbourhood variable influences surrounding land features is urban regions due to transformation of dense vegetation into agriculture near dense vegetative area may be promoted by cutting down vegetation. Proximity variable like distance to market, road, railways, hospitals, highways, schools etc. are the factors which everyone consider during housing and construction. Demographic variable like statistics of population demand is important to estimate the LULC change. Socio-economic variableslike land cost, time to travel, opportunity cost, tradition, status, education, etc. may be well considered before building houses. Institutional variable comprise the decision made by managerial authorities related to construction, industries and institutions suitability factor includes site suitability analysis for building houses, agriculture, etc. Economic variables like land tenure, farm size, income may be important to be considered. Climatic drivers such as climatic variability and life zones are considered while building their houses. Bio-physical drivers like topography, elevation, slopes, soil types, altitude are the variables which are considered while making decisions of or relating to construction (especially in disaster-prone areas) and Restriction variables may comprise prohibited area for development such as reserved forest, green belt, historical places, airport side area etc. (Clarke and Gaydos,

1998; Geist et al., 2002; Verburg et al., 2004; Akin et al., 2014).

LULC Change Modelling

Various LULC change and urban growth modelling approaches have been developed and reported in recent past, which should aim to address key aspects such as;

1.   Which socio-enviro and other variables bring most to an explanation of LULC changes - why?

2.   Prominent spatial locations of getting change - where?

3.   Rate at which LULC change is taking place- how much?

4.   What would be the future pattern of LULC- when?

The standard LULC change and urban growth modelling approaches have been reviewed and reported in literature extensively (Agarwal et al., 2002). Various approaches of LULC change have been classified and discussed in subsequent sections.

Modelling Approaches: Statistical and Machine Learning approach use historical observations of LULC changes to parameterise parametric and non-parametric relationships between spatio-temporal predictors and calibrate the model (Pijanowski et al., 2014).

Cellular Automata based-approach integrates suitability maps of LULC with neighbourhood effects and significant information required for projecting future LULC changes like different explanatory variables (Batty, 2005; Clarke and Gaydos., 1998).

Sector-based economic approach represent supply and demand by utilising general and partial equilibrium structural models for economic sectors within regions based on overall economic activity and trade (Parker et al., 2003).

Spatially Disaggregate Economic approach identifies the causal relationships influencing the spatial equilibrium in land systems by estimating structural form econometric models (Irwin et al., 2001).

Agent-based modelling approach is helpful in simulating actions of heterogeneous LULC change drivers that influence land surfaces decisions into the LULC system. Also, human behavioural approach can also be included into the modelling for better decision making (Veldkamp et al., 2001).

Hybrid approaches encompass different modelling approaches into a single modelling framework to enhance the potential of LULC change modelling so that better decision making can be done (Matthews et al., 2007).

Above discussed modelling approaches have been critically compared on the ground of pattern/ process, LULC, typical data requirements and key assumptions. Also, its uses have been recommended in detail (Table 1).

LULC Change Models

Empirical Statistical Models

Empirical statistical approaches can be used to establish relationship between LULC change and their explanatory variables. Relationships are derived empirically by fitting statistical data to assess LULC change explicitly. The multivariate analysis like multiple linear regression, logistic regression, multinomial regression, logit regression, etc., build the relationship between explanatory variables for potential contributions of empirically derived LULC changes. However, statistical relationship may not build the effective causal relationship and the regression model may poorly perform globally. Therefore, long-term predictions are quite challenging with this kind of modelling. This type of approach is better suited for analysing land use change and urban growth patterns on the basis of given historical data only and no further dynamism is considered. In most studies this is not valid.

Stochastic Models

LULC change and urbanisation are very complex, heterogeneous and stochastic in nature. This modelling approach mainly incorporates transitional probabilities for each cell of LULC/ urban growth and the decision of transition are based on a stochastic variable e.g. random number. The transition probabilities are measured by some statistical means, which determine changes from one LULC class to another class. This type of approach is useful for top-down relationship-based applications where impact assessment is an issue of concern. Effect of one variable on the phenomenon-based relationship can be effectively developed by such approaches. Although, transition probability based approaches are limited to their application as intensification of LULC change cannot be determined by the method because it is purely based on recent past data only (Xiubin, 1996). However, for incorporating intensification into stochastic models, some efforts have been put which are helpful to be effective on LULC change intensification.

Optimisation Models

Optimisation techniques are used to determine optimum combination of explanatory variables and their value ranges to explain the LULC & urban growth phenomenon. Optimisation techniques like linear and non-linear programming are generally incorporated into the economic models. In various applications like land chunks, by giving land characteristics and location as inputs, it is possible to identifiy the locations with highest rent. This modelling approach allows investigating the influence of various policies on LULC change (Lambin et al., 2000). It can be used for land allocation for optimal crop production. However, this modelling approach may suffer from the complexity of objective functions and ambiguous human behaviour like differences in values, culture and attitude. Though, at a generalised level, this can be underestimated but are likely to be significant when considered for small or fine scale LULC change processes.

Dynamic (process-based) Simulation Models

These models are based on the interaction of socio-economic and biophysical processes. Change in LULC patterns with time and space is determined by these processes. The dynamic process-based simulation models incorporate the interaction among all components to develop a spatially explicit dynamic system. The complex aggregate system is formed by combining small chunks analysis using differential equations. The prior understanding among variables is developed before simulation (Waddell, 2002). This modelling approach is more powerful in establishing the relationship among variables and simulating the dynamic behaviour of the system. Although, the relationship cannot be built into the system in a straightforward way, analysing LULC change with this method is complex as numerous interactions among variables take place.

Cellular Automata-based Models

Cellular automata (CA) is a cell-based framework which includes cell states, transition rules, infinite discrete cells and neighbourhood. CA-based models are very effective for addressing LULC change. Urban growth is a dynamic and complex phenomenon and CA includes the capability to model a complex phenomenon in an easy and effective manner (Clarke and Gaydos, 1998).

Integrated Models

Above discussion gives information about various types of LULC modeling approach. The recent advancement includes the integration of more than one approaches for providing added attributes to the LULC change modelling. Such modelling approaches are used where spatially explicit interaction and dynamic behaviour including long-term prediction, is required. However, it is very complex to hybrid two different modelling approaches for a large landscape as the number of interactions greatly increase (Lambin et al., 2000).

Variety of models have been used for LULC change simulation and discussed in above sections. These models are suitable for different applications, have different input data requirement, suitable for different temporal & spatial scale, have different computational requirements and based on different modelling approaches. There is no agreement among researchers and users about most suitable model. Individual model is suitable in a set of conditions and has different level of limitations also. Present study summarises and classifies the models into different categories based on their capability, suitability and modelling approach as presented in Table 2. The study discussed insights of LULC change models and modelling approaches which would help in selecting a suitable model for specific land use applications.

Table 1: Generalised Characteristics of Different Modelling Approaches

Modelling Approach	LULC Pattern/ Process	Land use (LU)/ Land cover (LC)	Crucial Stationarity	Data Required	Suggested Applications
Machine Learning and Statistical		LC	Strong stationarity	Historical LULC maps of at least to different time and different LULC explanatory layers.	Extrapolating historical LULC patterns and forecasting under stationarity
Spatially Disaggregated Economic Models	Pattern based modelling	LC	Utility or profit maximisation Price and/or spatial equilibrium Heterogeneous agents sometimes specified	Historical LULC data of different temporal, multiple driving factors like socio-economic, biophysical and proximity variables that influence LULC change decisions.	Efficient in building causal relationship among variables and LULC change and can simulate policy change effects on land market.
Cellular		LULC	Stationarity strong spatial control and/or interaction No market interactions	Historical LULC data of different temporal, multiple driving factors like socio-economic, biophysical and proximity variables that influence LULC change decisions.	Capability of long-term forecasting spatio-temporally even without market feedbacks.

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Table 1 (Contd.....)

Modelling Approach	LULC Pattern/ Process	Land use (LU)/ Land cover (LC)	Crucial Stationarity	Data Required	Suggested Applications
Agent-Based Models	Process based modelling	LULC	Usually heterogeneous agents Variable interactions among agents	Human behavioural characteristics in terms of agents, quantitative and qualitative data for decision making and historical LULC data of different time period.	Able to introduce behavioural characteristics into the model and human choices can easily be introduced.
Sector-Based Economic Models		LC	Heterogeneous agents sometimes specified Utility or profit maximisation Price equilibrium Representative agents	LULC information of multi-date and explanatory variables like economic variables (e.g. prices of commodities and values of trade at different scales) that influence LULC demand and supply.	Specifically utilised land economics based applications like demand and supply and land allocation. Also, short-term forecasting is feasible.

Table 2: Classification of LULC Change Models

Known information on LULC	Need to know on LULC	Modelling	Method/Approach
Historical spatio-temporal LULC data	Short-term prediction Causal relationship among variables and LULC change. Short-term LULC change prediction.	Stochastic modelling Empirical and statistical	Transitional probability models Multivariate statistical modelling
Historical spatio-temporal LULC data along with multiple causative factors	Long-term LULC change prediction spatio-temporally	Process-based modelling	Dynamic process-based simulation approach
	Causal relationship among variables and LULC change. Long-term LULC change prediction.	Agent-based modelling	Deterministic, stochastic and optimisation modelling approaches.

Discussion and Conclusion

A variety of approaches and models have been developed for assessment, monitoring and modelling of LULC changes and rural development over the last few decades, which includes Machine-Learning and Statistical Approaches, Cellular approaches, Sector-based Economic approaches, Spatially Disaggregate Economic approaches, Agent-based approaches and Hybrid approaches. Different approaches have their own framework to handle different types of drivers, variables, suitability and capability to handle complexity. There is no absolute agreement among users and research community about most appropriate approach. However, Cellular Automata-based approaches were found to be promising in modelling of LULC changes, which is very much evident from the number of its applications reported in the literature in recent past (Agarwal et. al., 2000). Comparison of different modelling approaches has been presented in Table 1. In recent past many LULC change models have been developed and reported, which are capable in modelling of these phenomena at different spatial and temporal scales with different complexities. Geospatial technologies and methods like remote sensing, geographical information systems (GIS), satellite based positioning solutions and terrestrial scanning techniques have opened a new era for geospatial data collection, data storage, manipulation, analysis of geospatial information and modelling of different processes and phenomena which have association with earth surface and geography. These technologies have provided a system for storing & retrieval of large volume of spatial data and to bring them to a common reference, scale and format. They have helped in incorporating the spatial influences in analysis of different rural development problems, which is otherwise not possible. These techniques have

also helped in incorporating the spatial and temporal variabilities of different input variables in modelling and analysis of a variety of problems and helped in reducing the uncertainties. LULC change modelling is a geospatial phenomenon and many of its drivers are also geographical in nature. The integration of geospatial techniques with different modelling approaches makes any modelling approach more promising by adding flexibility, spatio-temporal variability, dynamism, long-term predictability and visual analysis. Present study revealed that hybrid approaches may play an important role in determining most promising LULC change, rural development and prediction which is possible by incorporating geospatial techniques well in any modelling approach.

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