Role of Remote Sensing in Land Use and Land Cover Modelling

Nilimesh Mridha[1], Debasish Chakraborty[2], Aniruddha Roy[2] and Sushil Kumar Kharia[1]

[1]Division of Agricultural Physics
Indian Agricultural Research Institute, New Delhi – 12
[2]ICAR Research Complex for NEH Region,
Umroi Road, Umiam, Meghalaya 793103

Introduction

Land use and land cover (LULC) changes have been among the most significant noticeable human modification of Earth's terrestrial surface. Land surfaces comprising the physical and biological entities including vegetative cover, water bodies, barelands or artificial structures represent land cover (Ellis, 2007). Alternatively, land use refers to an intricate combination of socio-economic, management principles and economic purposes and its contexts for and within which lands are managed. We often designate land use and land cover together, but there is a distinct difference between the two. Land cover especially implies the spatial distribution of the various classes of land cover that can be assessed both qualitatively as well as quantitatively through remote sensing techniques, while land use mainly focuses on human activities determined by the integration of natural and social scientific methods in various landscapes even having same land cover (Lambin et al., 2001). LULC change is possibly the most obvious form of global environmental change visible at spatial and temporal scales having great relevance to our daily life (CCSP, 2003). Technically, LULC change is directly related with the mean quantitative changes in spatial extent (increase or decrease) for a specified type of land cover and land use respectively. Both anthropogenic and environmental forces largely affect the behavior of changes in land use and land cover (Liu et al, 2009). The land use/cover changes have been extensive in the past several decades in the North-Eastern region (Singh et al. 1996) leading to environmental degradation. Nandy et al. 2006 reported that Jhum cultivation in the eastern region has disrupted the ecological balance of the region due to soil erosion resulting from reduction of Jhum cycle. Understanding the changes in LULC and subsequent modelling is critical to the prediction of future land use change scenarios.

Need for estimation of land use and land cover change

For inclusive growth and development in various spheres and sectors, food and water security for the growing population needs to be met and issues emerging from climate change, need to be addressed (Ramakrishna, 1998). The pressure on the Indian land mass is almost 4–6 times the global average as Indian land area is only 2.3 % of global terrestrial area but harbours 17% of the global population and 11% of the global livestock. In the last 40 years the area under crop has almost remained constant at around 1402.0 Mha (Roy and Murthy, 2009). Over the decades, there was phenomenal change in the pattern of land use land covers. The various impact of LULC includes decrease in vegetation cover, biodiversity loss, climate change, carbon dynamics, environmental pollution and changes in hydrological regimes (Sohl and Sleeter, 2012). There are different factors which greatly affect land cover and land use. Various environmental factors like soil characteristics, climate, topography, and vegetation determine land cover and simultaneously land use is determined by demographic factors such as population, technology, political structures, economy, and systems of ownership, attitudes and values.

Remote sensing as a tool for land use and land cover change

There is ample collection of data produced from remote sensing and vary from the very high-spatial resolution images (such as CartoSat, IKONOS and Quickbird), to regional datasets produced at regular intervals (e.g., LISS III, TM/ETM, SPOT), to lower spatial resolution (>250 m) images now produced daily across the entire Earth (e.g., MODIS). The temporal dynamics of the synoptic view of the earth's surface by satellite assisted data capture has given us an important tool to study the variations in land use and land cover over a period of time. The changes in the land use and land cover manifested as a function of the changes either natural or manmade, have a bearing on the reflectance patterns of incidence radiation due to the changes in the vegetative cover, soil moisture or the various modifications of the earth's surface (Navalgund, 2001). Since the changes in land use and land cover are more or less unidirectional, without much oscillation, it is safe to extrapolate the changes in spatial extents and also calculate the rate of changes. A very important tool in this regard is the Geographical Information System (GIS). The Geographic Information System is a powerful tool in which spatial information can be stored, organized, and retrieved in a user friendly environment. The Conjunction of satellite remote sensing data and ancillary data in a GIS environment combined with the Global positioning system (GPS) data is a potential tool to environment management.

Land use and land cover change modelling

First and foremost in land use and land cover change modelling is the generation of scenarios. This is because the relationship of the people with the land has the same origin as their evolution –the ability to modify their surroundings to suit themselves. Land use change is a locally pervasive and globally significant ecological trend. On a global scale, nearly 1.2 million km2 of forest have been converted to other uses during the last three centuries while cropland has increased by 12 million km2 during the same period. Currently, humans have transformed significant portions of the earth's land surface: 10–15% is dominated by agriculture or urban industrial areas and 6–8% is pasture. These changes in land use have important implications for future changes in the earth's climate and, in turn, greater implications for subsequent land use and land cover change. The surface heat and moisture budgets depend very much on land use and land cover which, in turn, affect atmospheric instability. Simulations of the plausible human influenced landscape changes following different scenarios may reveal strategic policies that should be modified to improve the environment. For a particular region, current trends coupled with historical land use patterns are used to model future land use. Numerous models have been used to build scenarios of the future: narrative method models and hybrid methods using both qualitative and quantitative methods (Jones 2005). Agrawal et al. (2002) have provided an exhaustive study on the various available land use and land cover change models. Most land use/change models incorporate three critical dimensions. Time and space are the first two dimensions and provide a common setting in which all bio-physical and human processes operate. The third dimension is the human process or the human decision-making dimension. The three dimensions of land use change models (space, time and human decision-making) and the two distinct attributes for each dimension (scale and complexity) are the foundations of the land use change models.

Applications and Challenges of LULC modeling

Applications

- Provides support to understand the cause-effect relationships of land use dynamics

- Helps in sustainable land use planning and optimizing policy making decisions
- Valuable for unravelling the multifaceted suite of biophysical and socio-economic forces that impact the rate and spatial pattern of land use change
- For estimating the possible impacts of changes in land use

Challenges

- Primary challenge is the availability of spatially and temporally varied consistent data which are representative of driving forces.
- Linking remotely sensed outputs with social science analyses.

Basic Requirements for LULC modeling

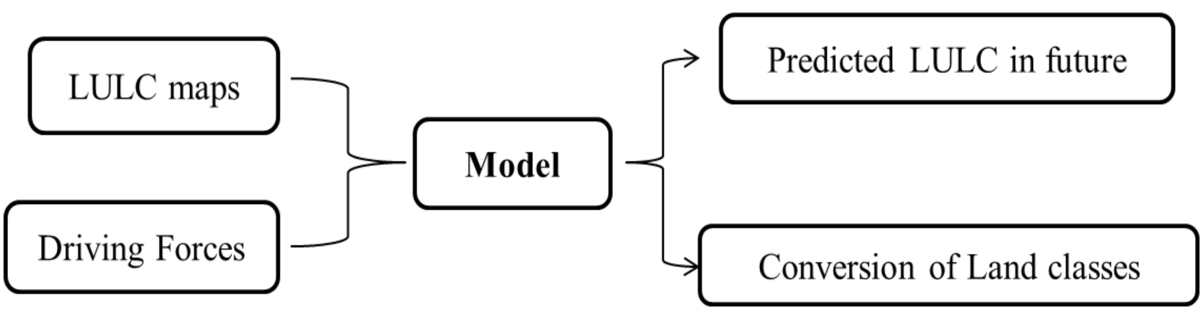
- Scenarios generation
- Historical and current land-cover maps
- Socio economic, biophysical and environmental data
- Identification of the driving forces

Models used for LULC change

Model Name	**Dependent Variable**	**Other Variables**	**Strengths**	**Weaknesses**
Conversion of Land Use and Its Effects- CLUE Model (Veldkamp and Fresco 1996)	Predicts future land cover scenarios	Human & Biophysical drivers	Wide range of biophysical and human drivers over several temporal and spatial scales	Inadequate consideration of institutional and economic variables
Cellular Automata model • RIKS model (Engelen et al, 1997) • SLEUTH model (Clarke et al, 1997) • Fuzzy CA model (Wu, 1996) • ANN CA model (Li et al, 2001a)	Periodical change in urban areas	Roads & Extent of urban areas, Elevation & Slope,	Allows each cell to act independently according to rules, analogous to city expansion as a result of hundreds of small decisions Fine-scale data, registered to a 30 m UTM grid	Does not unpack human decisions that lead to spread of built areas Does not yet include biological factors
LUCAS (Landuse Change Analysis	Transition probability	Land cover type (vegetation)	Model shows process, output	LUCAS tended to

System) (Berry et al. 1996)	matrix (TMP) (of change in land cover) Module 2 simulates the landscape change Module 3 assesses the impact on species habitat	Slope, Elevation Land ownership population density, Distance to nearest road Age of trees	and impact uses low-cost open source GIS software	fragment the landscape for low-proportion land uses, Patch-based simulation would cause less fragmentation
Area based model (Hardie and Parks 1997)	County level LULC predictions	Country level per acre basis land base, average farm revenue, crop costs, standing timber production costs & prices, Population	Uses free available data and landowner characteristics and population density Land heterogeneity Proivde county-level sampling error	Long-term forecasts run the risk of facing an increasing probability of structural change, calling for revised procedures

Steps of LULC modeling:



Use of Remote-Sensing Data in LULC Modeling

Remote sensing data of both historical and present time are extremely important for evaluating and monitoring changes in LULC parameters which are quite helpful in modelling LULC through scenario development, driving-force analysis, model parameterization, and model validation.

1. Scenario Development

Future land use scenarios are vital tool for various research interests such as land-use impacts on greenhouse gas emissions and climate, biodiversity, water resources and hydrologic change. Scenario-based approaches are used in numerous global environmental assessments and can also be used for simple projections of historical rates of LULC change. Sometimes modelling LULC change focuses on creating a single reference condition through extrapolation of historical trends, while adjusting certain LULC types for testing the hypothesis about future influences.

2. Driving-Force Analysis

It is increasingly important to note that the ultimate goal of studies on LULC change dynamics using remote sensing is to finding the primary driving forces of that change (Chowdhury, 2006). Linking remote-sensing information with ground-based social data and uses in LULC models can significantly increase our understanding of the primary drivers of LULC change. Remote sensing cannot directly observe and monitor the Governmental policy that has a foremost influence on LULC change, but can evaluate the impact of the policy on land use, letting LULC modelers to build qualitative and quantitative relationships between a policy driver and impacts on LULC change.

3. Model Validation

Model validation remains an under developed component of LULC modelling science due to dearth of data availability and not due to validation techniques available. Obviously, it is not possible to validate future projections of land use as no validation data are available for modeled future dates, so modelers naturally depend on historical period to accomplish model validation. Ray and Pijanowski (2010) used black-and-white aerial photography to validate model output for a backcasting application in the Muskegon River watershed in Michigan. However, LULC modelers give less importance on pixel-by-pixel accuracy assessments due to path-dependence and the inherent stochasticity of LULC-modeling processes.

Conclusions

Remote sensing is a very important tool for studying the change analysis of land use and land cover. LULC change negatively affects the patterns of climate and socio-economic dynamics in global and local scale. LULC models that link remote-sensing information with social data can greatly increase understanding of the primary drivers of LULC change. There is a vast scope of research on modelling LULC change dynamics over North-Eastern part of India that can give an insight of future projections on land use change.

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