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Modelling spatiotemporal land dynamics for a trans-boundary river basin using integrated Cellular Automata and Markov Chain approach

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A B S T R A C T

Nowadays, trans-boundary natural systems are facing land management issues due to conflicts of two territories. Thus, land dynamics information has great importance to understand the consequences of natural resources at spatial and temporal scales. In this study, spatiotemporal LU/LC modelling approach has been emphasized to address land resource problems of a trans-boundary river basin of Central India using satellite imagery data. An integrated Cellular Automata (CA)-Markov Chain (MC) model was employed over the Betwa River basin (BRB), located in Madhya Pradesh and Uttar Pradesh States, facing agriculture and water resource management issues. The spatiotemporal LU/LC pattern during 1972–2013 has been elaborated to focus changes in agriculture and waterbody area. Historical LU/LC analysis shows that 4.16% area under agriculture was accrued due to increased 1.62% waterbody in the BRB. However, after the year 2007 agriculture area is accrued by 1.75% mainly due to irrigation water availability from newly accomplished Rajghat reservoir. Further, the CA-MC model has been firstly validated, and then successfully employed to predict future LU/LC maps for the years 2020, 2040, 2060, 2080 and 2100. Future analysis shows that vegetation pattern may alter in future due to decline in dense forest (1.39%) and agriculture area (6.41%), which cease to increase in degraded forest and barren land by 4% and 4.23%, respectively. The modelling results depicted that 0.71% decrement in waterbody and subsequent decrease in the agriculture area by 6.41% could occur in future. The present study reveals that, changes in future LU/LC may lead to severe reduction in food productivity land of Central India. Therefore, it is evoked that integrated CA-MC modelling approach can interactively predict future LU/LC scenarios by furnishing some solutions to the current land resources problems.

1. Introduction

The trans-boundary river basins have major disputes of natural resources management (Dhliwayo, 2002; Wolf & Hamner, 2000) due to political and legislations issues (Dedina, 1995; Kindt, 1986; Singh & Gosain, 2004) that can potentially affects agrarian livelihood (Makalle, Obando, & Bamutaze, 2008; Wolmer, 2003). The Indian territory constitutes of major and medium trans-boundary rivers, and therefore adaptive land management strategies and environmental cooperation between countries/states are necessary for conservation of natural resources (Agrawal, 2000). Nowadays, changes in the land resources have been investigated using advanced remote sensing and GIS techniques. The land use/land cover (LU/LC) change analysis has been extensively carried out to understand spatiotemporal land dynamics for the studies on climate, ecology and food security (Fuchs, Herold, Verburg, Clevers, & Eberle, 2015; Vitousek, 1994). This information reveals ongoing process of deforestation (Geoghegan et al., 2001), biodiversity (Falcucci, Maiorano, & Boitani, 2007) and urbanization (Dewan & Yamaguchi, 2009). Also, LU/LC change has significant impact on hydrologic response (Shaw, Marrs, Bhattarai, & Quackenbush, 2014), stream-flow (Zheng, Yu, Deng, Wang, & Wang, 2012), water quality (Goldshleger, Maor, Garzuzi, & Asaf, 2015; Wang, Xu, & Zhang, 2014) and snow cover (Szczypta et al., 2015). It can significantly affect hydrology of the trans-boundary river basin (Mati, Mutie, Gadain, Home, & Mtalo, 2008). Therefore, spatiotemporal LU/LC maps are vital to monitor LU/LC changes (Herold, Mayaux, Woodcock, Baccini, & Schmullius, 2008), addresses climate change mitigation and adaptation (Turner & Annamalai, 2012),

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ecosystem evaluation (Nelson et al., 2009) and natural resources management (Bagan & Yamagata, 2012; Tallis & Polasky, 2009).

Previous research studies have been used different datasets (historic maps and remotely sensed data) to carry out LU/LC change analysis for the local or regional studies (Čarni, Jarnjak, & Oštir-Sedej, 1998; Bičık, Jeleček, & Štěpánek, 2001; Petit & Lambin, 2002; Kuemmerle, Radeloff, Perzanowski, & Hostert, 2006). These datasets are pre-requisite to prioritize and evaluate spatially explicit future LU/LC (Torrens, 2006). Nowadays, advanced geospatial data sets have been extensively used for monitoring important LU/LC features to explore human-environment interaction (Hoalst-Pullen and Patterson, 2010). Moreover, several advanced geospatial and statistical LU/LC models such as such as Markov Chain (MC) (Kamusoko, Aniya, Adi, & Manjoro, 2009), Cellular Automata (CA) (Han, Hayashi, Cao, & Imura, 2009; Mitsova, Shuster, & Wang, 2011), logistic regression model (Hu & Lo, 2007) and machine learning algorithms (Huang, Ding, & Zhou, 2010) are currently being used to understand and, to predict possible LU/LC pattern (Costanza & Ruth, 1998). Kamusoko et al. (2009) predicted future LU/LC for Zimbabwe, and reported increase in barren land area as potential threat to rural sustainability up to 2030. Guan et al. (2011) encountered decrease in agriculture and forest area with increase in settlement area for the period of 2015–2042 in Saga, Japan. He et al. (2013) assessed impact of farmland preservation policies on urban sprawl and food security in China. They concluded that urban land could increase in the future, and have susceptible impact on future land resources. Moreover, future LU/LC maps were predicted by Paegelow and Olmedo (2005) for the study area of Garrotxes (France) and Alta Alpujarra Granadina (Spain). Huang, Pontius, Li, and Zhang (2012) studied LU/LC transition intensity effect on the regional economic and ecological health in southeast China. Thus, it is observed that LU/LC modelling can significantly use to find out land resources problems.

Many researchers suggested that integration of two or more models will be useful to improve reliability of LU/LC prediction (Arsanjani, Kainz, & Mousivand, 2011; Guan et al., 2011; Kamusoko et al., 2009; Liu, Yu, Li, Li, & Lei, 2010; Mondal & Southworth, 2010; Myint & Wang, 2006; Qiu & Chen, 2008; Sang, Zhang, Yang, Zhu, & Yun, 2011). This approach has been employed effectively for LU/LC simulation using an integrated Cellular Automata (CA)-Markov Chain (MC) model (Kamusoko et al., 2009; Mondal & Southworth, 2010; Myint & Wang, 2006). The CA-MC model is widely used for spatial analysis, due to remote sensing and GIS ability to efficiently use temporal datasets in the model (Kamusoko et al., 2009). It has a more significant effect on the transition maps, which determine the quantity and location of the LU/LC changes. This model integrates Markovian transition probabilities and CA spatial filter which facilitate to significantly simulate future LU/LC maps based on historical LU/LC changes (Kamusoko et al., 2009). It addresses improved CA-MC model functions i.e. MC model reveals transition rules of CA model for future simulation (Liu, Li, Shi, Wu, & Liu, 2008). Hence, CA-MC modelling is robust approach in which, MC computes transition matrices based on amount of temporal changes among different LU/LC classes (López, Bocco, Mendoza, & Duhau, 2001), and CA controls spatial change pattern through local-raster based contiguity filter or transitional maps (Clarke, Brass, & Riggan, 1994; Li and Gar-On Yeh, 2004) to predict future LU/LC at discrete time steps (Guan et al., 2011). Therefore, CA-MC model employed in the present study has capability to simulate future LU/LC pattern.

In this study, historical and future LU/LC change analysis has been carried out for a trans-boundary river basin i.e. Betwa River Basin (BRB) of Central India. The study area has agriculture and water resources management problems due to disputes in the two territories of Madhya Pradesh and Uttar Pradesh States. Therefore, the present study has been planned with the specific objective of spatiotemporal analysis of historical LU/LC dynamics, and use of integrated CA-MC model for future simulation to identify possible land resources problems in the Betwa River Basin. The present study also emphasized the need of understanding changes in agriculture area corresponds to water resources availability in Central India.

2. Study area

Betwa River is tributary of the Yamuna River (which is tributary of Ganga River) located in Central India. It flows from south-western to north-eastern direction. BRB lies between 75° 05′ 38″ E to 80° 13′ 48″ E longitude and 22° 51′ 51″ N to 26° 3′ 5″ N latitude, and in the geo-graphical context of Madhya Pradesh (68.90%) and Uttar Pradesh states (31.10%) as shown in Fig. 1. The BRB covers approximately 43,936.59 km^2 of large geo-graphical area, and is dominated by black cotton soil. It is bounded by southern Vindhyan plateau and northern alluvial plains. It has land use covers of flat wheat-growing agriculture to steep forest hilly area with varying vegetation and topography in complex pattern. Most of the basin area is under cultivation of millet, wheat and gram as main crops (Sutcliffe, Agrawal, & Tucker, 1981). Forest is dense in South-East, apart from the clay plains. Also, some Northern part of the BRB covers partially distributed degraded or open forest area.

3. Data and methodology

In this study, historical LU/LC change analysis has been carried out using spatiotemporal satellite imagery data of post-monsoon season (Table 1). These imageries were obtained from the United States Geological Survey (USGS) Global Visualization Viewer (Glo-Vis) website (http://glovis.usgs.gov/) for the years 1972, 1976, 1991, 2001, 2010, and 2013. Furthermore, IRS-P6 imagery of LISS-III sensor was procured from National Remote Sensing Centre (NRSC) Hyderabad for the year 2007. The problem of different spatial resolution has been removed by scaling IRS-P6 (LISS-II) imagery data from high (23.5 m) to coarse (30 m) resolution. Then, these scaled images were utilized in LU/LC change analysis to avoid errors while predicting consistent LU/LC maps.

3.1. Historical LU/LC classification

The supervised classification algorithm is usually appropriate when relatively few classes are to be identified, or when training sites have been selected. It is the most common and easy image classification method, compared to other methods, uses spectral signatures in the training site. Therefore, in this study supervised classification method has been employed to prepare the LU/LC maps of the study area. Processing of satellite imagery data and their interpretation were carried out using ERDAS Imagine-2014 and ArcGIS 10.2.2 version software packages, respectively. The BRB area was classified into six LU/LC classes i.e. dense forest, degraded/open forest, agriculture area, barren land, waterbody and settlement. The dense and degraded forest types are classified based on canopy density. According to Forest Survey of India (FSI), land with canopy density more than 40% and less than 40% are termed as dense forest and degraded/open forest respectively. Difference in spectral resolution of forest canopy facilitated to distinguish these classes in the present study. Furthermore, agriculture class has been classified including both cultivated and non-cultivated crop land area.

For accuracy assessment, five hundred random points were generated across each LU/LC map. These points were then cross-checked with the reference data. In this study, Google Earth