Ecological Modelling 344 (2017) 29–37

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Integrating biophysical and socio-economic factors for land-use and land-cover change projection in agricultural economic regions

Anh Nguyet Dang[a,*], Akiyuki Kawasaki[b]

[a] School of Environment, Resources and Development, Asian Institute of Technology, 12120 Pathumthani, Thailand
[b] Department of Civil Engineering, School of Engineering, The University of Tokyo, Japan

ARTICLE INFO

Article history:
Received 31 March 2016
Received in revised form 1 November 2016
Accepted 7 November 2016
Available online 18 November 2016

Keywords:
Integration
Agriculture based economics
System dynamics
GIS
Biophysical factors
Socio-economic factors
Multi-logistic regression

ABSTRACT

Land-use and land-cover change (LUCC) are shaped by society–nature interactions and processes. Therefore, a full study of LUCC dynamics needs explicitly to take account of both socio-economic and biophysical factors. Although some studies have addressed both these drivers, most are built as a package/black-box and consider individual types of land-use rather than land systems as a whole. Our research aims to develop a comprehensive and flexible framework that links socio-economic and biophysical driving factors to project LUCC. The framework combines System Dynamics and Geographic Information System (GIS) models, with System Dynamics used to examine the relationship between socio-economic driving factors of LUCC processes and land demand estimates. The GIS model is used to allocate land demand to the most suitable grid cells, according to the different biophysical characteristics of the cells. The study is based on the application of the framework in Dak Lak province, Vietnam, where economic development has resulted in rapid LUCC. The Kappa value of our study, compared with actual land-use in the province (2010), is 0.87. It proves that our model is reliable and can help land-use planners and policy makers develop sustainable land-use planning and management strategies. Working on the assumption that the trends indicated in Dak Lak's 2020 land-use plan continue, we produced projected land-use/land-cover maps for 2020 and 2030.

1. Introduction

Land-use and land-cover change (LUCC) are the result of complex processes caused by both biophysical and human-related driving factors, and the interaction between these forces (Global Land Project, 2005; Lantman et al., 2011; LUCC, 2002; Milne et al., 2009; Turner et al., 1999; Verburg et al., 2009). Although affected by biophysical conditions, LUCC processes are influenced most by humans and their use of the land (Rounsevell et al., 2012; Turner et al., 2009). Static biophysical indicators are now accepted as insufficient to explain changes to land (Jackson et al., 2009). Therefore, models that analyse LUCC dynamics need to reflect human action; this will support more practical land-use management (Milne et al., 2009; Verburg et al., 2009). Taking human-induced factors into account increases the ability of models to simulate reality and the probability of consistent outputs.

Although efforts have been made to develop integrated LUCC models which connect biophysical and human-related factors, explicit inclusion of human-nature interaction mechanisms remains one of the major challenges in LUCC analysis (Rounsevell et al., 2012; Turner et al., 2007; Verburg, 2006). Most existing models, which take into account both biophysical and human-related factors, are built as a package/black-box and consider individual types of land-use at a certain scale rather than land systems as a whole (Liu et al., 2007, 2013; Luo et al., 2010). These include the International Institute for Applied Systems Land Use Change (IIASA-LUC) model, the Integrated Model to Assess the Global Environment (IMAGE), and the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), all of which are specific to the agricultural sector and are applied at a national or global scale (Strengers et al., 2004). This makes these models difficult to implement for other purposes and at other scales (Lantman et al., 2011). Furthermore, it is difficult to modify land-use change driving factors in these models, causing a gap between model-builders and scientists on the one hand, and end-users, including land planners and policy-makers, on the other. Throughout Asia, and especially Southeast Asia where populations are increasing rapidly and extensive economic development is expected, there is vital need for a framework to help decision makers produce better regional development plans. At the moment, it is difficult to apply package LUCC

* Corresponding author.
E-mail address: dang@ait.ac.th (A.N. Dang).

http://dx.doi.org/10.1016/j.ecolmodel.2016.11.004
0304-3800/

models to Southeast Asian regions as there is little extant research on LUCC and little data on which to base predictions.

Our study aims to develop an easily understood and transparent, flexible framework that links socio-economic and biophysical drivers to project LUCC. We do this by developing an integrated framework that couples System Dynamics (SD) and the Geographic Information System (GIS). SD was used to estimate land demand by analyzing various socio-economic driving factors. GIS models were used to allocate land demand according to the most suitable locations for each land-use/land-cover type. The model is expected to reflect LUCC more reasonably than other models by linking biophysical and socio-economic factors. In so doing, it will provide, new insights into the multi-scale manner of land-use change (the SD model covers the provincial/macro scale, the GIS model the grid/micro scale). Because the model is transparent, land planners and policy makers will be able to add and remove parameters easily to reflect different scenarios. This is a significant advantage over existing models.

Dak Lak province, in the central highlands of Vietnam, was selected for our case study. Our study projects LUCC in Dak Lak at 500 m resolution until the year 2030. The result map was validated by comparing it with an actual land-use map (2010) provided by the Department of Natural Resources and Environment (DONRE), Dak Lak. Hence, our study can assist land-use planning in Dak Lak and contribute to provincial policies for sustainable development. Authorities have recognized an urgent need for action in this regard (ADB, 2006; DONRE Dak Lak, 2012; MRC, 2015). The study's findings also contribute to a body of knowledge about LUCC in Dak Lak and Vietnam more generally.

2. Study area

Dak Lak is located in the central highlands of Vietnam (Fig. 1). Its total area is 13,125 km^2, and in 2012 there were 1.8 million inhabitants. Economic development, including domestic and foreign investment, has led to immigration from other provinces and in recent times there has been a significant increase in the population (Ty et al., 2009). The Asian Development Bank (ADB, 2006) and Mekong River Commission (MRC, 2015) have documented rapid LUCC in Dak Lak. Increasing population and greater investment has stimulated demand for agricultural land, which then is used primarily for infrastructure development and cash crops (coffee, rubber, sugar-cane). In turn, demand for land has led to a decrease in forest cover. The relationship between population and agricultural land is seen in Fig. 2. The Dak Lak land-use planning report for 2005–2010 (DONRE Dak Lak, 2012) shows a 14% increase (approximately) in the use of land for agriculture and an 11.1% increase in built-up land. LUCC in Dak Lak has directly and adversely affected the ecological and hydrological systems, soil properties, and local and regional climates (Müller, 2003).

For development in Dak Lak to be sustainable, efficient land-use management and planning is essential and urgently needed. LUCC studies have been conducted in the province, and in the Mekong river region which encompasses Dak Lak, but these take account only of land-use change analyses and ignore the influence of macro-level socio-economic variables. Müller and Munroe (2004) examined natural, social and economic issues in two Dak Lak districts (Lak and Krong Bong), but considered only two factors – policy and technology. Takamatsu et al. (2014) and Ty et al. (2012) noted the absence of socio-economic factors from LUCC projections for the Mekong river region. This is why planners in Dak Lak have underestimated land-use demand and changes in land-use type. For example, the actual area of land under agriculture in 2010 (4875 km^2) was 430 km^2 greater than the estimate (for 2010) advanced in 2005 (4445 km^2). To make effective and informed decisions, planners need better, more accurate information on which to base policy. This need is urgent.

3. Data and methodology

3.1. Data

Our model is built on spatial and non-spatial data collected from 2005 to 2010 (Table 1). (There was a change of administrative boundary in 2004. To use data from before that time would have meant risking inconsistency). With regard to non-spatial data, social-economic statistics – population, migration, labor forces, GDP, agricultural production, price of agricultural products, agricultural yield, agricultural investment – were taken from Dak Lak statistics yearbooks and the Dak Lak land-use planning toward 2020 report (DONRE Dak Lak, 2012). The scenario for our model drew on the policy and development trends outlined in the 2020 report, and information collected from World Bank (WB), ADB and MRC reports. With regard to spatial data, we used the Digital Elevation Model (DEM), land-use map, soil map, road and river map, and information about administrative boundaries and population density. The spatial data were converted into 500 m cell size grids for further analysis.

3.2. Methodology

SD was proposed by Jay W. Forrester in the 1950s to solve complicated management problems using a systems thinking approach. Over the last three decades, SD has been applied across disciplines. The applications of SD for understanding complex issues with regard to LUCC has been demonstrated in many studies (Costanza et al., 1990; Garedew et al., 2012; Liu et al., 2013; Rasmussen et al., 2012; Stéphenne and Lambin, 2001). However, SD lacks flexible spatial analytical capacity and rich visualization. For this reason, SD has been used in combination with other modelling techniques to project land-use change (Dang and Kawasaki, 2016). He et al. (2005), Shen et al. (2007), Han et al. (2009) and Lauf et al. (2012) combined SD with Cellular Automata; Zhan et al. (2007), Luo et al. (2010) and Zheng et al. (2012) used SD with CLUE; and Liu et al. (2013) drew on the combination of SD and hybrid particle swarm optimization (HPSO). We decided to combine SD with a GIS model in order to incorporate the spatial dimension to SD. GIS has enormous advantages for spatial analysis as ArcGIS is applied widely in many fields, including natural resources management and land-use planning. GIS can store, retrieve and present spatial information for complex LUCC allocation processes. However, GIS models lack a time dimension. SD covers the temporal dimension, which is a weakness of GIS. Thus, SD and GIS technologies complement each

Table 1
Spatial data used in our study.

No.	Input Data	Data type	Source
1	Land-use map Dak Lak 2005 and 2010, planned land-use map 2020 (250 m)	Polygon	Dak Lak DONRE
2	Boundaries	Polyline	Dak Lak DONRE
3	River map, Dak Lak	Polyline	Dak Lak DONRE
4	Road map, Dak Lak	Polyline	Dak Lak DONRE
5	Soil map	Polygon	Atlas Vietnam
6	DEM Dak Lak (30 m)	Raster	Mekong River Commission
7	Population 2005 (500 m)	Raster	Built based on land-use map 2005 and district level population of urban and rural residential areas