International Journal of Applied Earth Observation and Geoinformation 35 (2015) 175–186

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Dynamic simulation of vegetation abundance in a reservoir riparian zone using a sub-pixel Markov model

Zhaoning Gong[a,b,c,d,e], Tianxiang Cui[a,b,c,d,*], Ruiliang Pu[e], Chuan Lin[a,b,c,d], Yuzhu Chen[a,b,c,d]

[a] College of Resource Environment and Tourism, Capital Normal University, Beijing, PR China
[b] Key Laboratory of 3D Information Acquisition and Application of Ministry of Education, Beijing, PR China
[c] Key Laboratory of Resources Environment and GIS of Beijing Municipal, Beijing, PR China
[d] Base of the State Laboratory of Urban Environmental Processes and Digital Modeling, Beijing 100048, PR China
[e] School of Geosciences, University of South Florida, Tampa, USA

ARTICLE INFO

Article history:
Received 24 June 2014
Accepted 9 September 2014
Available online 29 September 2014

Keywords:
Vegetation abundance
LSMA
Sub-pixel Markov
Reservoir riparian zone

ABSTRACT

Vegetation abundance is a significant indicator for measuring the coverage of plant community. It is also a fundamental data for the evaluation of a reservoir riparian zone eco-environment. In this study, a sub-pixel Markov model was introduced and applied to simulate dynamics of vegetation abundance in the Guanting Reservoir Riparian zone based on seven Landsat Thematic Mapper/Enhanced Thematic Mapper Plus/Operational Land Imager data acquired between 2001 and 2013. Our study extended Markov model's application from a traditional regional scale to a sub-pixel scale. Firstly, Linear Spectral Mixture Analysis (LSMA) was used to obtain fractional images with a five-endmember model consisting of terrestrial plants, aquatic plants, high albedo, low albedo, and bare soil. Then, a sub-pixel transitive probability matrix was calculated. Based on the matrix, we simulated statuses of vegetation abundance in 2010 and 2013, which were compared with the results created by LSMA. Validations showed that there were only slight differences between the LSMA derived results and the simulated terrestrial plants fractional images for both 2010 and 2013, while obvious differences existed for aquatic plants fractional images, which might be attributed to a dramatically diversity of water level and water discharge between 2001 and 2013. Moreover, the sub-pixel Markov model could lead to an RMSE (Root Mean Square Error) of 0.105 and an R^2 of 0.808 for terrestrial plants, and an RMSE of 0.044 and an R^2 of 0.784 for aquatic plants in 2010. For the simulated results with the 2013 image, an RMSE of 0.126 and an R^2 of 0.768 could be achieved for terrestrial plants, and an RMSE of 0.086 and an R^2 of 0.779 could be yielded for aquatic plants. These results suggested that the sub-pixel Markov model could yield a reasonable result in a short period. Additionally, an analysis of dynamics of vegetation abundance from 2001 to 2020 indicated that there existed an increasing trend for the average fractional value of terrestrial plants and a decreasing trend for aquatic plants.

Introduction

Reservoir riparian zones are of essential ecologic land areas located between terrestrial and aquatic ecosystems, and play an important role in the exchange of water, carbon, and energy between the two types of ecosystems. As a special type of seasonal wetland ecosystem, reservoir riparian zones provide critical environments for development, evolution, and conservation of specific species (Wang et al., 2005). Vegetation, one of the crucial components of reservoir riparian zone ecosystems, plays a significant role in providing animal food and habitats, protecting biodiversity and maintaining ecological balance. As a critical indicator for measuring vegetation growth status, vegetation abundance is also important for evaluating reservoir riparian zone eco-environment (Guo et al., 2007). Thus, measuring and understanding the dynamic process of vegetation abundance is a prerequisite for assessing reservoir riparian zone ecosystems. Due to the suitability of remote sensing technology for large area mapping and its relatively low cost, many researchers have utilized satellite remote sensing imagery in analyzing vegetation dynamics in wetlands (Dronova et al., 2011; Kelly et al., 2011) and riparian regions (Ward et al., 2014) during last

* Corresponding author at: College of Resource Environment and Tourism, Capital Normal University, Beijing, PR China. Tel.: +86 18810449975.
E-mail address: txiang.c@gmail.com (T. Cui).

http://dx.doi.org/10.1016/j.jag.2014.09.004
0303-2434/

several decades. Moreover, the development of computer models for simulating the dynamics of ecological has brought a potentially solid and scientific basis for analysing vegetation abundance change (Liang et al., 2012; Sun et al., 2012; Lin et al., 2013).

Recently, numerous techniques have been developed for simulating ecological dynamics, which include regression analysis, Markov model, cellular automata model (Balzter et al., 1998), system dynamics model (Luo et al., 2010), artificial neural network (Ghiassi et al., 2005), Conversion of Land Use and its Effects (CLUE) model (Veldkamp and Fresco, 1996), and CLUE-S model (Verburg and Overmars, 2009). Among these techniques, the Markov model is a mathematical, conceptual model and it is a most straightforward successive model that has been used in land-use and land-cover change (LULCC) analysis and landscape pattern simulation in previous studies with a varying degree of success (Han and Chang, 2004; Li et al., 2009a,b). For example, in quantifying a process of land cover changes in southeastern Zambia, Petit et al. (2001) constructed three Markov transitive probability matrices to verify the simulation ability of a Markov model. And they predicted land cover distributions in the near future with three multispectral SPOT satellite images, which allowed to address the spatio-temporal patterns of land cover change in south-eastern Zambia. Wang et al. (2010a,b) simulated a land use pattern of the Yellow River Basin, China with the Markov model after analysing a time series of land use data derived from Landsat Thematic Mapper/Enhanced Thematic Mapper Plus (TM/ETM$^+$) images. Their study laid a foundation for investigating driving factors. To put forward suggestions for the optimization of land use, Liu et al. (2009) simulated and predicted LULC patterns of Guansi River Valley, China in the next 15 years based on the Markov model after tracking change trajectories from 1995 to 2005. Similar studies with successful application of the Markov model were also performed to Estonia by Aaviksoo (1995), Ohio, USA by Boerner et al. (1996) and Jialing River Watershed, China by Wu et al. (2012). In addition, the Markov is also applied to vegetation dynamic simulation. For instance, using five land cover maps extracted from five SPOT satellite images, Chuang et al. (2011) applied the Markov model to the vegetation restoration assessment, and their research found that vegetation restoration is on-going in Central Taiwan after a catastrophic earthquake. To evaluate patterns and causes in landscape dynamics in the Niger Delta, Alex and Blackburn (2011) derived the transitive probability matrix from two forest landscape maps and performed a forward Markov simulation to generate the future status of forests. Their research indicated an urgent need for appropriate environment policy development and implementation in the study region. Further, a Markov process of vegetation dynamic in the entire arid area of north-western China was analyzed and tested by Wang et al. (2010a,b) who found that a long-term average transition matrix could be reliably used to predict the dynamics of vegetation. Liu et al. (2012) also predicted characteristics of grassland using the Markov model based on a transitive probability matrix between 2000 and 2010. By a relative extensive literature review, previous studies have demonstrated that an integration of remote sensing (RS), geographic information system (GIS), and Markov modeling is an important and effective tool for analysing ecological dynamics.

Although many previous studies have been performed to generate vegetation abundance information (Elmore et al., 2000; Small, 2001; Shabanov et al., 2002; Small and Lu, 2006; Tooken et al., 2009; Hu et al., 2010), both analysis of vegetation abundance in a reservoir riparian zone and dynamics simulation of vegetation abundance have received little attention. Additionally, while researchers have exploited Markov model in simulating ecological dynamics at regional scale using traditional land cover transitive probability matrices derived from "hard" classifications, only a few of their studies were related to a sub-pixel Markov model. Therefore, the objectives of this study are (1) to derive vegetation abundance information in a reservoir riparian zone from moderate resolution Landsat TM/ETM$^+$/Operational Land Imager (OLI) images; (2) to assess the accuracy of derived vegetation abundance by using the sub-pixel Markov model; (3) to determine its applicability in simulating vegetation abundance; and (4) to predict the dynamics of vegetation abundance in the near future. This study will help us understand the vegetation dynamic patterns in a reservoir riparian zone with a hope to pay attention, especially for our study area, Guanting Reservoir Riparian zone, which has been undertaking vegetation decreasing and ecosystem degrading over the past several years. Additionally, our study extended Markov model's application from a traditional regional scale to a sub-pixel scale, which may enrich Markov model's application fields.

Study area and datasets

Study area

Guanting Reservoir is located in the north-western Yanqing District, Beijing (40°13′46″ N–40°25′42″ N and 115°34′2″ E–115°49′30″ E). Topography of the study area is complex with high elevation mountainous areas located in the northwest and flat areas located in the southeast. As a water-controlling project for the Yongding River, Guanting Reservoir covers an area of 253 km^2, contains about 2.3 billion cubic meters of fresh water, and provides around 300–400 million cubic meters water each year (He et al., 2008). This area is located in a transition zone between a sub-humid warm temperate region of the North China Plain and an arid warm temperate region of the Inner Mongolia Plateau. It has a continental semi-humid and semi-arid monsoon climate. Thus, precipitation is of monsoonal origin and the rainy season lasts from June to August. The average annual temperature is between 2 and 8 °C and the mean annual precipitation is between 370 and 480 mm (Wang et al., 2009). Due to the moderate climate, macrophytes, hygrophytes, mesophytes and halophytes are broadly distributed in this area (Zhen et al., 2012). However, in the past several years, soil erosion and water pollution have caused vegetation decreasing and ecosystem degrading in the Guanting Reservoir Riparian zone (Zhou et al., 2005).

Our study area (Fig. 1) was determined after analyzing fluctuations in water flow during 1989 and 2013. The Guanting Reservoir Riparian zone was divided into long-term exposure and long-term flooding regions by considering the frequency of flooding or exposure. The former represents exposure frequency is higher than flooding frequency, and the latter represents the contrary. The long-term exposure region covers an area of 42.06 km^2, while the periodic flooding region occupies 46.19 km^2. This study focuses on the dynamics of vegetation abundance after 2001.

Datasets

According to our surveys, various plants grow vigorously during August and September, which is proper for the extraction of vegetation information. In this study, seven cloud-free Landsat TM/ETM$^+$/OLI images acquired in years 2001, 2004, 2007–2010 and 2013 were used. All images were acquired at the end of August or early September to reflect almost the same growth status of vegetation in our study area (Table 1). Six bands (band 1–5 and band 7) of Landsat TM/ETM$^+$, seven bands (band 1–7) of Landsat OLI with 30 m spatial resolution were used in our study, all images covered the visible, near-infrared and short-wave infrared wavelengths. In addition, a scene of Worldview-2 imagery acquired on July 26, 2011 was also collected for a validation purpose to validate spectral unmixed results.

All seven Landsat images were georeferenced by manually selecting ground control points (GCPs) from a 1.8 m Worldview-2