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Analyzing urban ecosystem variation in the City of Dongguan: A stepwise cluster modeling approach

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ABSTRACT

In this study, a stepwise cluster modeling approach (SCMA) is developed for analyzing urban ecosystem variation via Normalized Difference Vegetation Index (NDVI). NDVI is an indicator of vegetation growth and coverage and useful in reflecting urban ecosystem. SCMA is established on a cluster tree that can characterize the complex relationship between independent and dependent variables. SCMA is applied to the City of Dongguan for simulating the urban NDVI and identifying associated drivers of human activity, topography and meteorology without specific functions. Results show that SCMA performances better than conventional statistical methods, illustrating the ability of SCMA in capturing the complex and nonlinear features of urban ecosystem. Results disclose that human activities play negative effects on NDVI due to the destruction of green space for pursuing more space for buildings. NDVI reduces gradually from the south part to the north part of Dongguan due to increased gross domestic product and population density, indicating that the ecosystem in Dongguan is better in the south part. NDVI in the northeast part (dominated by agriculture) is sensitive to the growth of economy and population. More attention should be paid to this part for sustainable development, such as increasing afforestation, planting grass and constructing parks. Precipitation has a positive effect on NDVI due to the promotion of soil moisture that is beneficial to plants' growth. Awareness of these complexities is helpful for sustainable development of urban ecosystem.

1. Introduction

Ecosystem is the important carrier of natural resources, as well as the foundation for providing favorable environment for human beings (Anderson et al., 2017). Vegetation, covering approximately 70% of earth's land surface, is an indispensable part of ecosystem and the main provider of ecosystem services in urban environment (Davies et al., 2017; Vieira et al., 2017). However, urbanization, as well as climate change, has led to alterations in vegetation patterns, which typically become reduced, fragmented and dispersed (McDonald, 2008; Dainese et al., 2017; Paul et al., 2018). For example, the global forest area decreased by 1.5 million km^2 from 2000 to 2012; around 49.2% of global grasslands have suffered from degradation (Hansen et al., 2013). For China, grassland area reduced by 17 million hm^2 from 2005 to 2016; agricultural land decreased by 318×10^3 hm^2 from 2011 to 2016 (Wang et al., 2018). Such reductions have threatened nature reserves, flood plains, public parks, and wildlife habitats (Pickard et al., 2017). Moreover, vegetation degradation would largely impact adsorptions of greenhouse gases and air pollutants (e.g., sulfur dioxide and nitrogen dioxide), resulting in aggravated heat island effect and pollution (Kim et al., 2016). Urban ecosystem is also plagued with problems of water pollution, soil loss and landscape fragmentation (Arneth, 2015). In order to keep urban ecosystem sustainability, it is desired to monitor spatiotemporal change of vegetation and understand the response of vegetation variation to human and natural factors (Zewdie et al., 2017).

Normalized Difference Vegetation Index (NDVI), corresponding to a nonlinear combination of Near-Infrared and Red band derived from the moderate-resolution imaging spectroradiometer (MODIS) products, is an efficient indicator for monitoring vegetation due to its simplicity and close relation to vegetation growth and coverage (Jarchow et al., 2017). Previously, NDVI was widely used for exploring the spatiotemporal dynamics of vegetation with statistical methods including correlation analysis, linear regression, and Mann-Kendall (Zhao et al., 2015; Bardhan et al., 2016; Levin, 2016; Shiflett et al., 2017; Tayyebi et al., 2018). In detail, Zhao et al. (2015) employed a geographically weighted regression method to investigate the spatial dynamics of NDVI in the

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north of China; strong spatial heterogeneity between NDVI and climate condition was analyzed over space. Bardhan et al. (2016) developed a bivariate correlation approach for simulating the relationship between NDVI and built-up area in Kolkata (the densest city of the world); negative impacts of high built-up area on green spaces were found. Levin (2016) used Mann-Kendall method for identifying the complex relationships among NDVI, agriculture, urban, forestry and wildfire dynamics in Israel, revealing that human activities were the most important drivers of landscape transformation. Jiang et al. (2016) compared a linear regression model with an artificial neural network (ANN) for estimating Alberta's NDVI under changes of precipitation and temperature; better performance was obtained by ANN. In general, the previous studies mainly concentrated on the effects of climate and human factors on NDVI in a temporal scale, ignoring the spatial variations due to topographical heterogeneity. Addressing this complexity could help fully understand the drivers of NDVI and instruct land use sustainability.

On the other hand, the distribution of vegetation is impacted by many factors including topography, climate, transportation infrastructure, planning, cultural practice and social preference (Dobbs et al., 2017). These factors are intertwined together, resulting in a network-structured urban ecosystem as well as leading to the spatial variation in vegetation being complex and ubiquitous (Enqvist et al., 2014). Moreover, due to tremendous heterogeneities in socio-economic, climatic and topographical features, as well as the interactions among them, the relationships between NDVI and environment are always plagued with complex features such as nonlinearity, and non-stationarity, especially in highly heterogeneous areas (Zhao et al., 2015). The conventional statistical methods could not well capture such complexities between NDVI and driving factors. Therefore, more robust approaches are desired to quantify the changing trend of NDVI and detect associated variation drivers. As a multivariate statistical approach, stepwise cluster analysis (SCA) is effective in capturing the inherent nonlinear/discrete relationships between the predictors and predictands through cluster trees, which are derived from a series of cutting or merging actions based on given criteria (Fan et al., 2015). SCA is also advantageous in projecting multiple inputs into predictions without assumption of determined linear/nonlinear functions. SCA has been successfully applied to environmental systems management, such as air quality prediction, climate projection, and streamflow forecast (Huang, 1992; Fan et al., 2015; Zhuang et al., 2016); however, few applications to the assessment of urban ecosystem variation were reported (Zheng et al., 2017).

Therefore, this study is to develop a stepwise cluster modeling approach (SCMA) for simulating NDVI to analyze spatial variation in urban ecosystem. SCMA could reflect the nonlinear/discrete relationships between multiple driving factors (e.g., human activities, topographic characteristics, and meteorological factors) and NDVI. Then, SCMA will be applied to the City of Dongguan, where different scenarios corresponding to changes in inputs will be set for predicting potential spatial distributions of NDVI. Besides, multivariate linear regression (MLR), multivariate nonlinear regression (MNR) and support vector machine (SVM) methods will be conducted for further illustrating the applicability of SCMA in urban ecosystem simulation. The obtained results are expected for providing useful information to support urban ecosystem sustainability.

2. Study system

2.1. Study area

The City of Dongguan (located between 22°39′N-23°09′N and 113°31′E-114°15′E), part of the Pearl River Delta urban agglomeration, is in the middle of the Guangzhou-Shenzhen economic corridor (as shown in Fig. 1). This city spreads over 32 towns and covers 2465 km^2 with more than 8.26 million inhabitants in 2016. The topography in

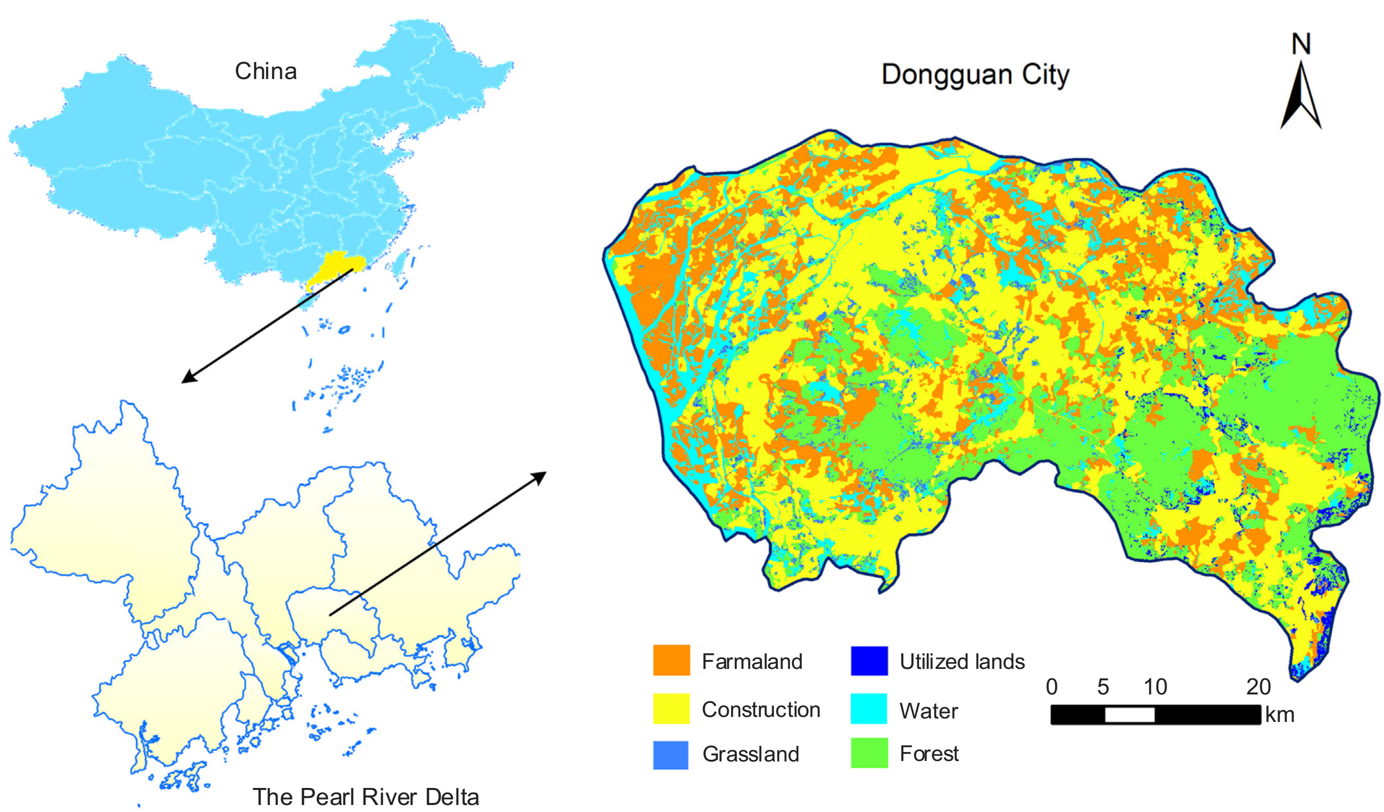

Fig. 1. The study area.