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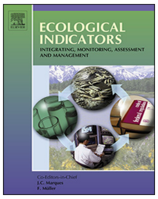

Original Articles

Factor analysis for aerosol optical depth and its prediction from the perspective of land-use change

Wenting Zhang[a], Qingqing He[b], Haijun Wang[c], Kai Cao[d,*], Sanwei He[e]

[a] College of Resources and Environment, Huazhong Agricultural University, Wuhan, China
[b] Department of Geography and Resource Management, The Chinese University of Hong Kong, Hong Kong
[c] School of Resource and Environmental Science, Wuhan University, Wuhan, China
[d] Department of Geography, National University of Singapore, Singapore
[e] School of Public Administration, Zhongnan University of Economics and Law, Wuhan, China

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ABSTRACT

This paper presents the non-stationarity and autocorrelation (with a Moran's I index score of 0.75) of the MODIS-retrieved aerosol optical depth (AOD) of the Wuhan agglomeration (WHA) in Central China, using geographically weighted regression (GWR) to identify the spatial relationships between AOD and its impact factors. In addition to the socio-economic factors, i.e., GDP and population, vegetation cover, elevation, land-use density and landscape metrics are also considered. Faced with the rapid process of urbanization and the impact of land-use change on AOD, which has been confirmed in previous studies, we propose an AOD prediction method, combining a land-use change simulation model, a cellular automata and Markov chain (CA-Markov) model, and spatial relationships built by GWR to represent the spatial distribution of AOD in 2030. The results suggest that the GWR model is able to address the spatially varying relationships, with an R-squared value, corrected Akaike's information criterion (AICc), and standard residual better than those of the ordinary least squares (OLS) model. Land-use simulation, with an accuracy of 89.76%, indicates that an increase in the built-up area and a decrease in the forest area will be the major trends of land-use change and will lead to increased AOD. The AOD simulation results indicate that the most developed areas, i.e., the cities of Wuhan and Huangshi, will be the AOD increase hot spots in the WHA. This study provides an alternative method to identify the varying spatial relationships between AOD and its impact factors. A spatial prediction method for AOD is developed from the perspective of land-use change, which will help land-use planners in decision making.

1. Introduction

Aerosol optical depth (AOD) is a measure of aerosol loading, integrated through the atmospheric column (Gupta et al., 2016). Since aerosols are one of the main pollutants that affect air quality (Xu et al., 2014), AOD has been employed as a principal indicator to describe atmospheric conditions. It is critically important to study the spatial and temporal changes in AOD to detect air pollutants, especially in China with its rapid industrial expansion and urbanization over the last few decades (Zhang and Cao, 2015) and the increasingly common occurrence of haze or smog episodes in the most developed and highly populated city clusters (Zhang and Cao, 2015; Wang et al., 2017a).

Massive studies have concerned and analyze driving factors for AOD with facilitation of Remote sensing technique, which has become a new means of monitoring global AOD (Xu et al., 2014). For example, using correlation analysis, Li et al. (2010) found that the distribution of aerosols was greatly affected by population, urban/industrial activity, agricultural biomass burning, spring dust, topography, and humidity. Guo et al. (2012) retrieved AOD data from MODIS aerosol data and used a linear regression model to identify the impact of the driving factors on AOD in Hubei, Central China, and found that the annual AOD was negatively related to elevation and the normalized difference vegetation index (NDVI) but positively related to population density. He et al. (2016) retrieved AOD over China from 2002 to 2015 and found that high aerosol loadings were usually located in economically and industrially developed areas, whereas low aerosol loadings were located in the rural and less developed areas of western and northeastern China. Li and Wang (2014) used MODIS data to investigate the spatial and temporal variations in AOD in Guangdong, a highly developed province in China. Linear regression was used to investigate the relationships between AOD and its driving factors, including the normalized difference vegetation index (NDVI), elevation, the urbanized

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[*] Corresponding author.
E-mail address: geock@nus.edu.sg (K. Cao).

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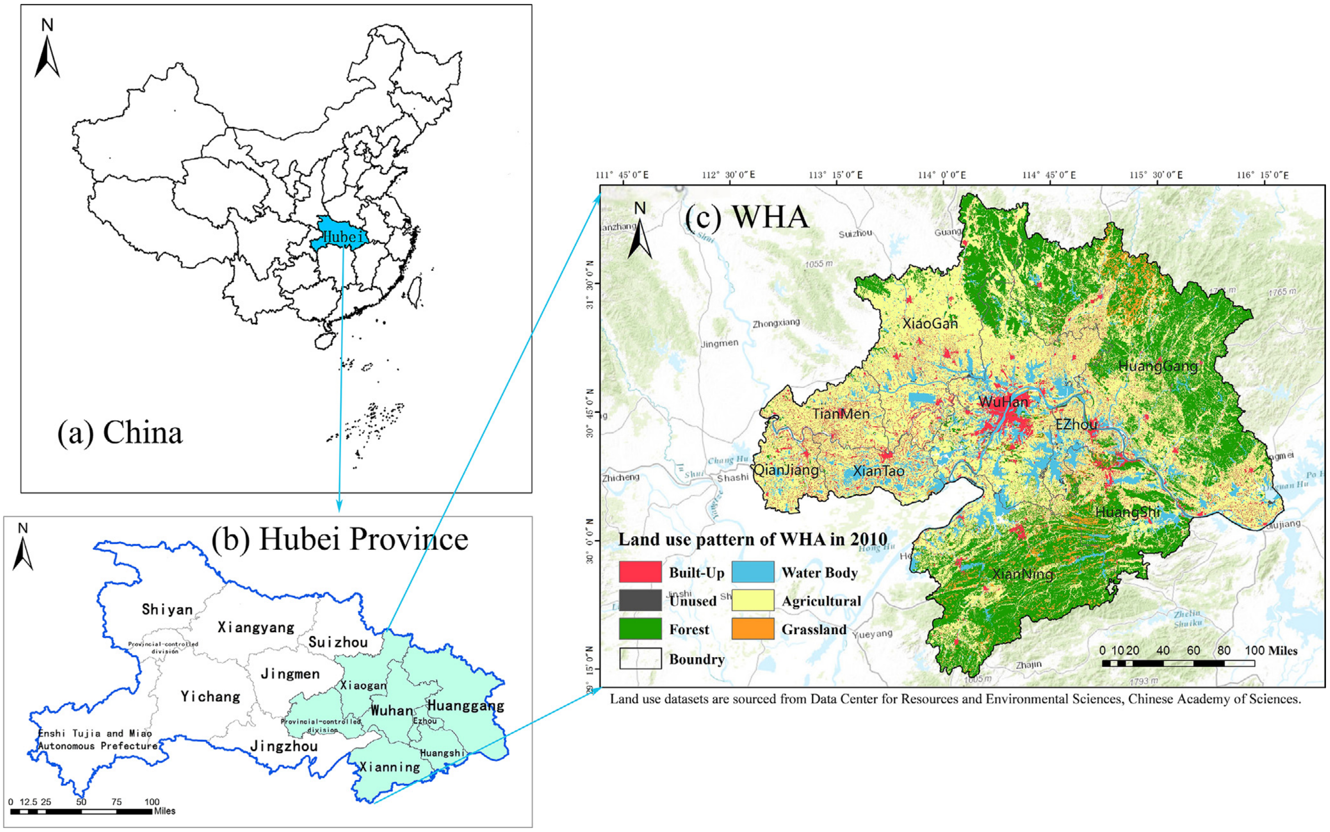

Land use datasets are sourced from Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences.

Fig. 1. Location and land-use pattern of the Wuhan agglomeration. (a) presents the location of Hubei Province in China, (b) presents the location of WHA in Hubei Province, and (c) presents the land-use pattern of WHA in 2010.

land fraction, and several socio-economic variables. Evidently, existing studies have widely implemented to find out the driving factors of AOD, and meaningful conclusions have been achieved.

Even if massive studies on driving factors analysis for AOD have been carried out, little concerns the spatial autocorrelation and spatial non-stationarity of AOD. Specifically, in previous studies linear models were the most popular means to represent the spatial relationships between AOD and its driving factors. However, traditional linear regression methods, such as ordinary least squares (OLS), ignore important local variations in the model parameters and are not able to address spatial autocorrelation and spatial non-stationarity that exist in the dependent and independent variables (Tu and Xia, 2008). In using OLS, it is assumed that the relationship is consistent between locations and that no spatial autocorrelation exists. However, this assumption is not always true in the case considering the relationship between AOD and its impact factors. For example, Li and Wang (2014) reported that AOD was strongly negatively correlated with NDVI in Guangdong, China (R-squared value of 0.782), whereas in the study conducted by He et al. (2016), a weak relationship between AOD and NDVI was found for the whole of China. With the respect to the spatial autocorrelation and spatial non-stationarity of AOD, it is significant to use a specific method that can identify local relationships rather than global relationship for AOD and its impact factors. A technique known as geographically weighted regression (GWR) is necessary to be used to discover the spatially varying relationship between AOD and its impact factors, which is capable of addressing issues with spatial autocorrelation (Zhang et al., 2004) and spatial non-stationarity (Fotheringham, 2001) issues. In our case study area, i.e., the Wuhan agglomeration (WHA), the AOD had a z-score of 111.65 and a Moran's I index value of 0.75, which indicates there is less than 1% likelihood that the spatial distribution of AOD is the result of random chance. Therefore, for the AOD in the WHA, GWR should replace the normally used OLS model to identify the spatial relationships between AOD and its impact factors.

Moreover, existing studies merely focused on historical relationship between AOD and its impact factors, and little presents possible spatial distribution in future concerning the rapid land use/land cover change. Under the rapid urbanization process in China, land use/land cover is changing dramatically (Zhang et al., 2010; Hu and Zhang, 2013) and numerous studies have confirmed that massive urban areas are positively correlated with higher AOD (Guo et al., 2012; He et al., 2016; Xu et al., 2014). However, few studies have focused on the spatial distribution of AOD in the future under rapid urbanization and land-use change. Thanks to the rapid development in geospatial simulation models, it has become increasingly possible and popular to design or predict land-use change in the future (Sang et al., 2011). In addition, In this study, to fill this gap, we attempt to represent the future spatial distribution of AOD using a future land-use pattern simulated by an integrated land-use cellular automata (CA) simulation model and Markov chain, termed CA-Markov, which is one of the most popular and commonly used models for simulating land-use change (Sang et al., 2011; Yang et al., 2014).

In summary, this study attempts to identify the non-stationary spatial relationships between AOD and its impact factors and to then predict AOD based on simulated land-use change. The proposed method was validated through testing, conducted in an urban agglomeration in Central China that is experiencing rapid urbanization, i.e., the WHA. In this study, we first analyze the spatial relationships between AOD and its driving factors using GWR, which can address spatial autocorrelation. A well-developed and popular land-use simulation model, the CA-Markov model, is then used to represent land use in the study area in 2030. Finally, using the spatial relationships identified by GWR and the future land-use pattern, the spatial distribution of AOD is predicted to facilitate the decision making process in land-use planning and environmental conservation. The remainder of this paper is organized as