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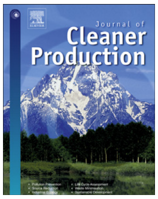

Spatially varying patterns of afforestation/reforestation and socio-economic factors in China: a geographically weighted regression approach

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ABSTRACT

Afforestation and reforestation play an important role in reducing global greenhouse gas emissions, and they are a component of the Reducing Emissions from Deforestation and Degradation-plus program. Within a theoretical analysis framework, we identified the key factors of afforestation and reforestation using a global regression model. Spatial non-stationarity of the key factors required the use of a geographically-weighted regression approach. Results indicated that afforestation and reforestation were affected by five main factors in China: population density, the gross output value of forestry, forest area, sown area of crops, and burned area due to forest fires. The gross output value of forestry had a negative correlation with afforestation and reforestation, which showed a decreasing trend from southeast to northwest in China. The population density and forest area were positively correlated with afforestation and reforestation in the northwest of China, but negatively correlated with those activities in other parts of China. The sown area of crops had a significantly positive correlation with afforestation and reforestation with an increasing trend from west to east. Forest fires also had a positive correlation with afforestation and reforestation, with an increasing trend from east to west in China. Policy-making should consider the spatial heterogeneity of the factors of afforestation and reforestation in designing REDD+ of China.

1. Introduction

Almost 12–20% of global anthropogenic carbon emissions are caused by deforestation and forest degradation (Van der Werf et al., 2009). In response, the United Nations Framework Convention on Climate Change (UNFCCC) put forward the “Reducing Emissions form Deforestation and Degradation (REDD)” program in 2007 (UNFCCC, 2007). Subsequently, China and India advocated for the expansion of the program to include the sustainable management of forests provided by afforestation and reforestation activities; they contended that the associated carbon sequestration and emission reductions benefits have the same value as reducing deforestation and forest degradation (Vijge and Gupta, 2013). The international community accepted their proposal in 2009 and REDD was converted to REDD+ (Pistorius, 2012). The new REDD+ program is not only concerned with forest protection, but also regards sustainable forest management, biodiversity conservation, and increased forest carbon storage to be equally important (UNFCCC, 2009). Kameyama et al. (2016) found that investment in low-carbon development program could be realized in Asia, and they estimated that an annual investment of 125–149 B USD would be needed in the region by 2035.

Afforestation and reforestation activities as a measure to enhance forest stocks have become a part of REDD+, because they constitute part of the voluntary and mandatory carbon offset trading scheme (Schirmer and Bull, 2013). Although it remains ambiguous about whether the ‘plus’ in REDD+ includes

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afforestation/reforestation (AR), such interventions in existing forest areas should be included in REDD+, such as restoring forest (Angelsen et al., 2012). Afforestation refers to the planting of trees on land with no forest cover in recent history (at least 50 years), while reforestation refers to the replanting of trees on land that was recently forested (Hamilton et al., 2010). China has implemented a large-scale tree-planting program in the country's arid regions to combat desertification (Lu et al., 2016). Since the founding of the People's Republic of China in 1949, China's forest cover has increased to 21.6% through large-scale afforestation, reforestation; China's afforestation and reforestation have reached 6933.38 M ha during 1949–2013, which was ranked first in the world (National Bureau of Statistics of China , 2014). Most afforestation and reforestation programs aim to provide multiple ecosystem services, such as preventing wind erosion, fixing mobile sands, climate regulation, and reducing pollution (Wang et al., 2011). However, there are still some commercial monoculture plantations in Southwest China, such as rubber, palm oil, and eucalyptus (Smajgl et al., 2015), which may reduce biodiversity (Li et al., 2007); these commercial monoculture plantations are not included in our analyses within this paper.

To maximize carbon sequestration in the future, exploiting the full potential of China's afforestation and reforestation efforts is crucial. It will be necessary to identify and analyze the factors that influence afforestation and reforestation. Given the vast territory of China, there are substantial differences in socioeconomic conditions and biological diversity among regions. To better understand these regional differences, provide effective tools for policy initiatives, and fully exploit the potential of afforestation and reforestation efforts, the spatial distribution of factors that influence afforestation and reforestation should be considered (Aguiar et al., 2007). Matthews et al. (2014) emphasized that the area with high complexity should be focused on considering the issue of spatial distribution and heterogeneity. The spatial variation of carbon dioxide emissions is more significant in forest land than that in other types of land (Husnain et al., 2014). According to analyzing the socio-economic factors of deforestation in Amazon, Okumura et al. (2015) proposed a new methodology based on geostatistics to describe the actual carbon-accumulation distribution of forest. However, the majority of studies are mainly concerned with the factors of deforestation and forest degradation rather than afforestation and reforestation. Only a few amount of literature has focused on the factors of afforestation and reforestation. For example, Machado et al. (2013) analyzed the factors of eucalyptus reforestation in Brazil through using system dynamics to simulate forest growth. Factors that influence deforestation (Geist and Lambin, 2002) and forest degradation (Morales-Barquero et al., 2015) patterns have been studied extensively, but understanding factors that influence afforestation and reforestation is limited (Frayer et al., 2014), and the regional distribution of those factors is even less well understood (Wyman and Stein, 2010).

The main contribution of this paper is to establish a new analytical framework to identify factors influencing China's afforestation and reforestation efforts, and to analyze the spatial distribution of those factors throughout China. The geographically weighted regression (GWR) model proposed by Fotheringham et al. (1996) can be used to estimate the parameters. GWR can not only test the spatial non-stationarity of the input variable, but it can also be used to estimate the outcome variable (Wheeler, 2013). The specific explanation for the GWR model is given in Section 3. This paper will first analyze the potential factors of afforestation and reforestation in China, and identify the key factors using a suitable global ordinary least square (OLS) regression model. Based on the test of spatial stationarity of the regression model, this paper tries to establish a GWR model to analyze the spatial heterogeneity of factors, which can provide several new insights to improve afforestation and reforestation policy and REDD+ design in China.

2. Literature review

There has been relatively little research on the potential factors of afforestation and reforestation in China. Motel et al. (2009) believed that macroeconomic variables might influence emission reductions related to deforestation. The relationship between economic development and AR is complex. On the one hand, increased economic development can stimulate the demand for agricultural products, resulting in the demand for agricultural land. Consequently, there is a decline in afforestation and reforestation as well as forest carbon storage. On the other hand, economic development may also increase the demand for forest protection, thereby reducing the pressure on forests (Ewers, 2006) and increasing forest carbon storage. Having explored the influence of climate governance on corporate social responsibility, Leventon et al. (2015) found that economic development opportunities could provide incentives to preserve the forest in Zambia. Similarly, Ooba et al. (2015) suggested a suitable system of carbon offsets is the key to promote the conversion of plantations to natural forests.

Deforestation can be a serious threat in regions with increasing populations, such as in Asia and Africa where many forests have been converted to farms, or in Latin America where forests are often converted to pastures (Achard et al., 2002). Increasing population can induce an increase in the demand for agricultural products, which stimulates the demand for agricultural lands (Okumura et al., 2015). At the same time, the increase in population can result in increased population densities. Consequently, land carrying capacity will also have to increase. Increasing demands for food and fuel typically accompany population growth, which often leads to predatory deforestation and a drastic reduction in forest area. Not only are a large number of forests often destroyed, but also the ability to recover forest resources and services may be severely weakened, and eventually forest degradation becomes more serious (Vieilledent et al., 2013).

Agricultural development may also lead to land use change (LUC), i.e. the conversion from forest land to agricultural land. Thus, more lands will be used for agriculture rather than for afforestation or reforestation (Culas, 2012). However, increased agricultural efficiency can increase production per unit area of land, which may reduce the pressure on land and lead to an increased likelihood of afforestation and reforestation (Choi et al., 2011), thereby enhancing the afforestation and reforestation potential of a country.

Culas (2012) found a negative correlation between AR and forest area. A large forest area makes the forest resources be no longer scarce, resulting in the popularity of logging. Local residents will prefer deforestation rather than afforestation or reforestation (Onojeghuo and Blackburn, 2011). Increased forest area also means a smaller proportion of farmland, which may result in more conversion from forest to farmland. However, large forested areas may also encourage more afforestation and reforestation. Development of forestry technology and techniques may also influence rates of afforestation and reforestation, and intensive forest management can increase the supply of forest products and increase deforestation. However, intensive forest management might also encourage forest sustainable management to improve forest value and yields (Chomitz et al., 2007), which may increase afforestation and reforestation. Finally, Lewandrowski et al. (2014) revealed that the uncertainty of potential disasters could have a significant impact on afforestation and reforestation efforts. Increases of forest loss related to disasters may also increase afforestation and reforestation efforts (Barbieri and Carr, 2005).

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