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Original Articles

Prediction of ecological effects of potential population and impervious surface increases using a remote sensing based ecological index (RSEI)

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ABSTRACT

The ecological impact of urban development and population increase is an area of increasing relevance as human modification of the landscape continues unabated. The prediction of this impact will help inform urban planning and decision making around population growth, impervious surface (IS) increase and associated ecological effects. The Xiong'an New Area is a state-level new area to be established in North China. The population growth goal for the area is going to reach 2.5 million and the area is planned to expand to 2000 km^2. The potential population growth and area expansion will result in a massive increase in IS area and thus may impact the regional ecological quality. A clear understanding of the impact would help to minimize the influence of the new area's development on regional ecological quality. Therefore, this study investigated current land cover types and ecological status in the Xiong'an New Area using feature inversion techniques and the improved remote sensing-based ecological index (RSEI). Statistical models were developed to predict ecological effects responding to the forthcoming population and associated IS increase in the new area. This was achieved by relating population growth to IS area increase and exploring the relationships between IS area and RSEI. The results show that the area's land surface has not been intensively developed and the current ecological status is good. The RSEI-based prediction shows that IS area has a noteworthy effect on regional ecological conditions. The variation of IS proportions in the new area can result in a significant shift of RSEI. A balance amount of total IS area in the 2000 km^2 new area is 433 km^2. Exceeding/reducing the amount would result in a decline/rise of the area's ecological quality. Introducing a quantity of IS area-related population density (IPD) reveals that the area's ecological quality is actually related to IPD rather than to traditional population density when the total area and future population of the new area are given. Therefore, the forthcoming regional master planning for the new area should include specific efforts to control IS area increase.

1. Introduction

The ecological impact of urban development is an area of increasing relevance as human modification of the landscape continues unabated. Increasing human activities have been associated with changes in land use and the intensification of construction practices on natural landscapes (Williams et al., 2009). Problems associated with urban environmental degradation are increasingly a threat to the world as the ecological changes within urban landscapes account for a growing share of global environmental change (Ellis et al., 2006). The current worldwide urbanization has caused a series of urban problems, such as congestion, water-logging, heat island effect, and air pollution. Therefore, green ecological development for a new city is an important issue to be considered and must be given priority by regional planners in the construction of a new city.

The Xiong'an New Area is a state-level new area to be established in the Baoding area of Hebei province, North China, starting from April 2017. Located closely to Beijing, the area will serve as a development hub for the Beijing-Tianjin-Hebei economic triangle, as well as a place for "non-core" functions of the Chinese capital Beijing to migrate to. It can be expected that a new city would soon stand on the north China plain, just like the Shenzhen Special Economic Zone in Guangdong province. The planning population target for the area is 2.5 million with a population density of 1250 people/km^2 and the area is planned to expand to 2000 km^2. The population growth will demand more spaces for work, living and various social activities and thus causes a massive increase in impervious surface (IS) area and a consequent decrease in natural landscapes. Obviously, population growth and associated IS

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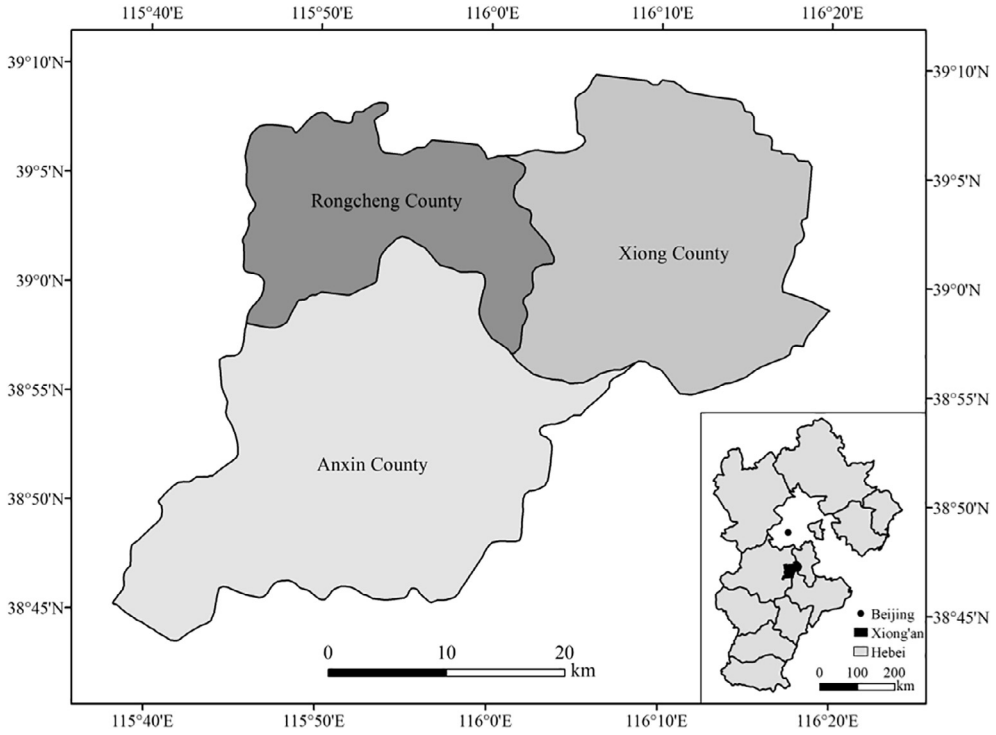

Fig. 1. Location map of the Xiong'an New Area.

increase are the main causes for downgrade of regional ecological quality. Accordingly, population and IS area criteria in regional planning are important factors for evaluating their potential impact on regional ecological quality and hence are important parameters used to determine the degree of the impact. Prediction of the effects of the population and IS growth on regional ecological quality may have great practical significance for a green development plan of the new area.

Recent advances in the satellite-based Earth observation system have the potential to become a powerful ecosystem management tool that can give a robust indication of ecosystem status from local to global scales (Ellis et al., 2006; Willis, 2015). Uses of satellite data for measuring different components of an ecosystem have the ability to identify ecological attributes in a wide range, as remote sensing measures reflected radiation of ground targets and thus is able to estimate properties of the Earth's surface such as land cover type, leaf area index, and biomass for each image pixel (Reza and Abdullah, 2011; de Araujo Barbosa et al., 2015). Therefore, remote sensing techniques have been widely used in ecological and environmental investigations (Kennedy et al., 2014). Remote sensing-based ecological monitoring and change detection have been carried out nationwide in China for a period between 2000 and 2010 (Ouyang et al., 2014) and in United States protected areas (Willis, 2015).

Various remote sensing based ecological indicators have played an important role in quantifying and mapping ecosystem properties and functions. Of them, the normalized difference vegetation index (NDVI) is the most commonly used single indicator applied in various ecological studies to characterize vegetated areas (Tilt et al., 2007; Ochoa-Gaona et al., 2010; White et al., 2016). Other single ecological indicators such as PVF (permanent vegetation fraction) and hyperspectral flower index (HFI) have also been suggested as good ecological indicators. Ivits et al. (2009) employed the PVF to estimate the favourable and unfavourable ecological status of the riparian zones in Andalusia. Chen et al. (2009) developed the HFI to monitor flowering status and flower phenology in the Tibetan Plateau. Remote sensing derived land surface temperature (LST) has also been frequently used to characterize urban heat island (UHI) (Nichol, 2009; Coutts et al., 2016; Xu et al., 2017). Schwarz et al. (2012) used air temperature and LST to quantify UHI in the city of Leipzig (Germany) and found that remote sensing derived LST could be more reliable in identifying heat islands in areas with a dense urban fabric than those with a lower population density.

Aggregated remote sensing based ecological indicators have also been applied in spatially-explicit assessment of complex ecological conditions through a combination of existing metrics and data. Tiner (2004) formulated a composite indicator that combined the habitat extent and habitat disturbance indices to provide an overall numeric value for natural habitat within Delaware's Nanticoke River watershed. A remote sensing based forest disturbance index was developed by Healey et al. (2005). The index was aggregated by a combination of rescaled three components (brightness, greenness, and wetness) of tasseled cap transformation, with increasingly positive values indicating greater likelihood of forest disturbance. Xu (2013) integrated four indicators (greenness, wetness, dryness, and heat) to generate a completely remote sensing-based ecological index (RSEI) and applied the index in assessing ecological conditions in Fuzhou city, China. The results suggested that the RSEI could effectively reveal regional ecological quality.

At present, the utility of remote sensing indicators as a tool to predict the impact of population growth on ecological quality remains a challenge since many economically important metrics, such as population, cannot be assessed efficiently by remote sensing alone. Attempts to predict future ecological change due to population growth using remote sensing data derived indicators have not yet been made, to the best of our knowledge. In addition, the existing ecological indicators have rarely been applied in urban and rural planning practice (Lakes and Kim, 2012). Therefore, this paper aims to (1) predict the impacts of population growth on the average ecological condition by relating it with impervious built area change, (2) demonstrate an approach on how an ecological index can be transformed into direct application for urban green development, and (3) provide the baseline ecological index map for the predevelopment stage of the Xiong'an New Area, based on an investigation of the latest land surface coverage status and ecological quality of the area using the improved RSEI indicator. The results will help inform urban planning and decision making around population growth, IS increase and its associated ecological effects.