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Urbanization-induced ecological degradation in Midwestern China: An analysis based on an improved ecological footprint model

Wen Luo[a], Hongtao Bai[a,b,*], Qiaonan Jing[a], Ting Liu[a], He Xu[a,**]

[a] College of Environmental Science and Engineering, Nankai University, Tianjin, 300350, PR China
[b] MOE Key Laboratory of Pollution Processes and Environmental Criteria, Nankai University, Tianjin, 300350, PR China

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ABSTRACT

Urbanization is the primary driving force for regional social economic development, and China's government is likely to continue promoting urbanization in the Midwestern part of the country. Yet, urbanization in this region has seriously damaged the fragile ecological environment. To explore the urbanization-induced ecological pressure in Midwestern China, the traditional ecological footprint (EF) model was improved in this study and the concept of "local EF" was proposed. By applying the improved model, the eco-environmental pressure from the process of urbanization in Midwestern China from 2005 to 2020 was estimated. The results showed that from 2005 to 2014, the urbanization in Midwestern China had gradually increased the eco-pressure, and it is predicted to continue to increase till 2020. The central region has the greatest eco-pressure. Because it is China's major grain production area and a large number of urban agglomerations have formed here. The eco-pressure in the west was relatively low. However, because this region is a major energy and chemical industry base of China, this eco-pressure cannot be underestimated. In the future, technological innovations will reduce the ecological impact in Midwestern China. But the promotion of higher living standards and consumption induced by urbanization would continue to exert tremendous pressure on the eco-environment. Therefore, the local government should strive to incentivize the return of its elite talent to their hometowns. The local government also need to build a green industrial chain to promote industrial upgrading and greening in Midwestern China. Doing so would help reduce the pressure on the fragile eco-environment.

1. Introduction

Over the past decades, China has witnessed dramatically accelerated urbanization (Deng et al., 2015), as the urbanization rate increased from only 17.4% in 1970 to 55.6% in 2015 (World Bank, 2016) and is projected to reach 76.0% by 2050 (UN, 2014). China issued the *National New Urbanization Plan* in 2013, in which the urbanization level is expected to reach approximately 60.0% by 2020.

Urbanization in Midwestern China lagged far behind urbanization in China, as shown in Fig. A1. However, with the promotion of national policies in recent years, the process of urbanization in Midwestern China has accelerated. For instance, an important goal of China's new urbanization policy is to enable around 100 million rural residents to live in local towns and cities in Midwestern China by 2020 (Xiong, 2016). China will also actively cultivate and develop urban agglomerations in Midwestern regions (State Council, 2014). In addition, the implementation of China's "Belt and Road" initiative will increase investment in traffic infrastructure in Midwestern China and promote urbanization in these regions. This initiative will also speed up urbanization. For each percentage point increase in urbanization in China, the need for fossil fuels will increase by 6.98×10^3 million tons (standard coal), the need for water will increase 1.71×10^2 billion cubic meters, the domestic wastewater discharge will increase 1.25 billion tons, and the increase of industrial solid waste will be 84.8 million tons (Zhao, 2015). Such huge resource and energy consumption and pollutant emissions will inevitably cause serious damage to the fragile environment of Midwestern China (Yuan et al., 2018).

Midwestern China plays an important role in the ecological structure of the country and the world. Yet, the ecological environment in Midwestern China is fragile, especially in Western China. Western China is an important water and soil conservation area. Besides, Western China has diverse ecosystems with important ecological

Abbreviations: EC, ecological carrying capacity; ec, per capita ecological carrying capacity; EF, ecological footprint; ef, per capita ecological footprint; es, per capita ecological surplus; ed, per capita ecological deficit; EII, ecological impact intensity; GDP, Gross Domestic Product; gha, global hectare; RMB, China Yuan

* Corresponding Author at: MOE Key Laboratory of Pollution Processes and Environmental Criteria, Nankai University, Tianjin 300350, PR China.
** Corresponding Author.
E-mail addresses: baiht@nankai.edu.cn (H. Bai), seacenter@nankai.edu.cn (H. Xu).

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functions (Zhou et al., 2002). The forests, grasslands, wetlands, ice and snow in western China constitute a complete ecological barrier zone, which is important to China and the rest of Asia (Huang et al., 2018). Central China is an important grain producing area (Wang and Wang, 2016). Therefore, in the process of urbanization in Midwestern China, policy makers should pay close attention to the change in eco-environmental pressure. The spatial and temporal distribution of water resources in Midwestern China is uneven. Therefore, it is of great significance to study the pressure on the eco-environment from the process of urbanization in Midwestern China.

The ecological footprint (EF) is a comprehensive indicator for evaluating the eco-environmental pressure caused by human behaviors (Wang et al., 2017). EF refers to the total area of biomass productive land that is needed to produce resources for a given population and to absorb the wastes produced by those populations from consumption (Wackernagel and Rees, 1996). To measure regional sustainable development, the EF model converts human consumption of resources, and the resulting environmental pollution, into the required ecologically productive land area and compares it with the ecologically productive land area that can be provided by the actual resource utilization level, based on the specific economic level of a region (see, for instance, Al-Mulali et al., 2015). Over the years, the research scale of EF has varied from the micro to the macro. For the macro scale, it included grand engineering projects (Li and Wen, 2018), cities (Nixon and Fulweiler, 2012), countries (Gao and Tian, 2016), and even the world (Jorgenson and Rice, 2005). For the micro scale, it referred to families (Klein-Banai and Theis, 2011), schools (Kuzyk, 2012), the process of construction and demolition waste (Marrero et al., 2017). The research object has expanded from land to water (Luo et al., 2018), energy, and other ecological components (Moore et al., 2013). Among them, water footprints (Hoekstra et al., 2012) and carbon footprints (An and Xue, 2017) are the two most important research fields of EF. Moreover, the EF was also used as a tool to study the regional ecological security pattern and to estimate the ecological impacts of economic and social development (Uddin et al., 2017).

Recent studies on EF have focused on consumption (Fan et al., 2017). However, from the perspective of the pressure on a particular regional environment, due to the existence of interregional trade, the environmental impact caused by regional consumption may not necessarily be borne by the consuming region. At the same time, the EF is not only influenced by consumption locally, but also partly by consumption in other places. Besides, the human consumption of ecological resources and its impact on the eco-environment in a region was measured by comprehensively calculating the EF of six kinds of ecologically productive lands (Lenzen and Murray, 2001). The six kinds of ecologically productive lands are listed in Table A1. However, water resources and water environmental functions are extremely important for economic and social development in most areas, particularly ecologically fragile areas where water resources are scarce. In the EF model, the definition of water, as one of the six major types of productive lands, refers only to the biomass production function of water. However, biological production is only a function of water areas. Water resources play a vital role in maintaining the ecological environment and social production.

In recent years, some scholars have combined the EF model with emergy analysis, life cycle theory, the input–output method, non-linear artificial neural network (ANN) models (Wang et al., 2018), and other models to promote authenticity and reliability in measuring ecological impact and pressure (Alvarenga et al., 2012). Zhao et al. (2005) modified the EF calculation method by attempting to combine it with emergy accounting. Siche et al. (2010) discussed some weak points found in Zhao's approach and proposed a new approach called Emergetic EF. Chen and Chen (2007) conducted a time series (1981–2001) of Chinese society to compare the emergy-based EF with EF. The results suggested that the emergy-based EF was better than EF for illustrating the ecological overshoot of the general ecological system. Zhen et al. (2017) used the Footprint Investment per unit of Footprint Delivered as an indicator of the sustainability of an ecological system based on the Emergetic EF method.

The world average productivity of all types of ecologically productive land is the key factor in the measurement of EF. As most of the global average data quoted in research domestically and globally came from WWF's *Living Planet Report* (WWF, 2014) and *National natural capital accounting with the EF concept* (based on 1993 data), there was a lack of timeliness and practicability in the variation of output each year. Moreover, applying the world average productivity and equilibrium factor calculated by international agencies cannot truly reflect the actual ecological differences among regions. The ecological environment in Midwestern China has its own characteristics. To reflect the ecological pressure in the process of urbanization in this region more accurately, it is necessary to localize the parameters when applying the EF model.

In this study, the EF model was used to measure the pressure on the eco-environment in Midwestern China. In view of the existing deficiencies of the traditional model, three improvements were proposed. First, we proposed the concept of a local EF, which used the production volume to calculate the EF of biomass (EF of the cultivated land, grassland, forestland, and waters, where waters refer to the material production functions) and used the consumption volume to calculate the EF of energy land and construction land. Second, a seventh type was added to the EF account: EF of water resources. Third, when calculating the EF of biomass, we localized parameters. We replaced global hectare with national hectare and revised the equilibrium and yield factor based on the concept of the national hectare. In addition, the least squares regression method was used to predict the ecological pressure in Midwestern China in 2020.

2. Methodology and data

2.1. Improved EF model

First, to reflect the ecological pressure on the environment of a

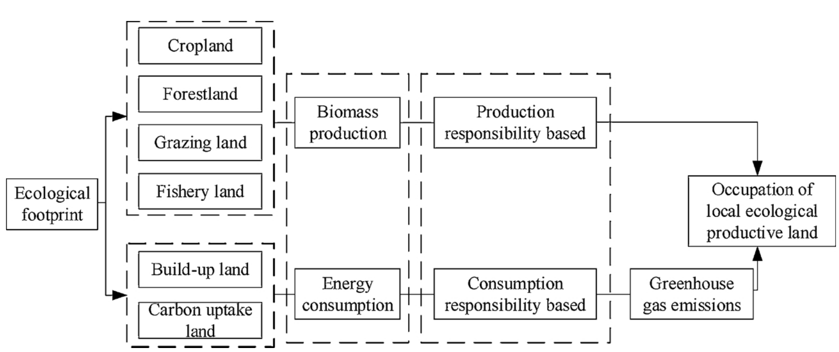

Fig. 1. Connotation schematic of EF.