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Comprehensive evaluation of the regional Atmospheric Environment Carrying Capacity: Model development and a case study in China

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ABSTRACT

Atmospheric environment is a complex system affected by economy, society, population and other factors. Based on DPSIRM framework, scientific relationships among those factors were reflected and inherent mechanism of the complex system was studied. 20 indicators were selected to construct an evaluation index system. Optimizing Projection Pursuit by Simulated Annealing algorithm, the Coupling Simulated Annealing-Projection Pursuit model was established to calculate a comprehensive index, which was used to evaluate the regional Atmospheric Environment Carrying Capacity. The results showed that the Driving force and Pressure subsystems occupied a leading position on the whole system. Economic development, urbanization process, population growth and pollutant emission needed to be concerned to maintain the harmony of the complex system. Influence weights of indicators were quite different from each other. The top 5 indicators were: the amount of industrial smoke and dust emissions, the amount of automobile, the comprehensive energy consumption of 10,000 Yuan industrial output value, the annual average wind speed and the number of days of air quality reached the national standard's second level. By analyzing the evaluation results, Atmospheric Environment Carrying Capacity was on the rise in 2006–2015, which suggested Chengdu's atmospheric environment showed a good condition during these years. However, with the rapid industrialization, urbanization and accompanying pollution, we should boost the corresponding exhaust gas treatment capacity to keep its environmental healthy.

1. Introduction

At present, the development of our economy and society still relies mainly on the resources consumption and pollutant emission. Atmospheric environmental deterioration and environmental carrying capacity weakening are prominent gradually. The environmental problems have increasingly become a bottleneck restricting the social and economic development (Liu, 2011). Atmospheric Environmental Carrying Capacity (AECC) describes the ability of atmosphere to consume and reduce various polluting gases (Santoso et al., 2014). This ability depends on several factors, such as economic development, regional industrial structure, energy structure, technical level, population, resources, geographical and meteorological conditions, environmental protection investment and others (Zhou, 2010). Evaluation of AECC can be used to judge whether the atmospheric environment meets the requirements of sustainable development. Its evaluation content is to estimate the urban air pollution and environmental protection management in the current socio-economic development.

The widely used evaluation methods of environmental carrying capacity include comprehensive evaluation method (You et al., 2016; Zeev et al., 2015; Cheng et al., 2015), ecological footprint method (Liu et al., 2016; Richard and Manfred, 2003; Chen et al., 2014), system dynamics method (Fang and Liu, 2010; Zhou and Zhou, 2017) and so on. Among them, the comprehensive evaluation method can evaluate the regional carrying capacity by various indicators which reflect the social, economic, environmental and ecological conditions. It can integrate all of indicators into one comprehensive index. So, its calculation result is comprehensive and its process is relatively simple. The commonly used comprehensive evaluation methods include analytic hierarchy process (Peng et al., 2011), Pressure-State-Response (PSR) model method (Wei et al., 2014; Wang et al., 2014; Zheng et al., 2015;), vector model method (Wang, 2008), fuzzy comprehensive evaluation method (Wang and Pan, 2014), principal component analysis method (Zhang et al., 2017) and others. Driving force-Pressure-State-Impact-Response-Management (DPSIRM) model was created based on PSR model. Compared to PSR, DPSIRM model separated the Driving force subsystem from the Pressure subsystem, the Impact subsystem from the State subsystem, and the Management subsystem from the Response subsystem. DPSIRM model can be used to explore the inherent mechanism of 'economy- society-atmospheric environment' complex

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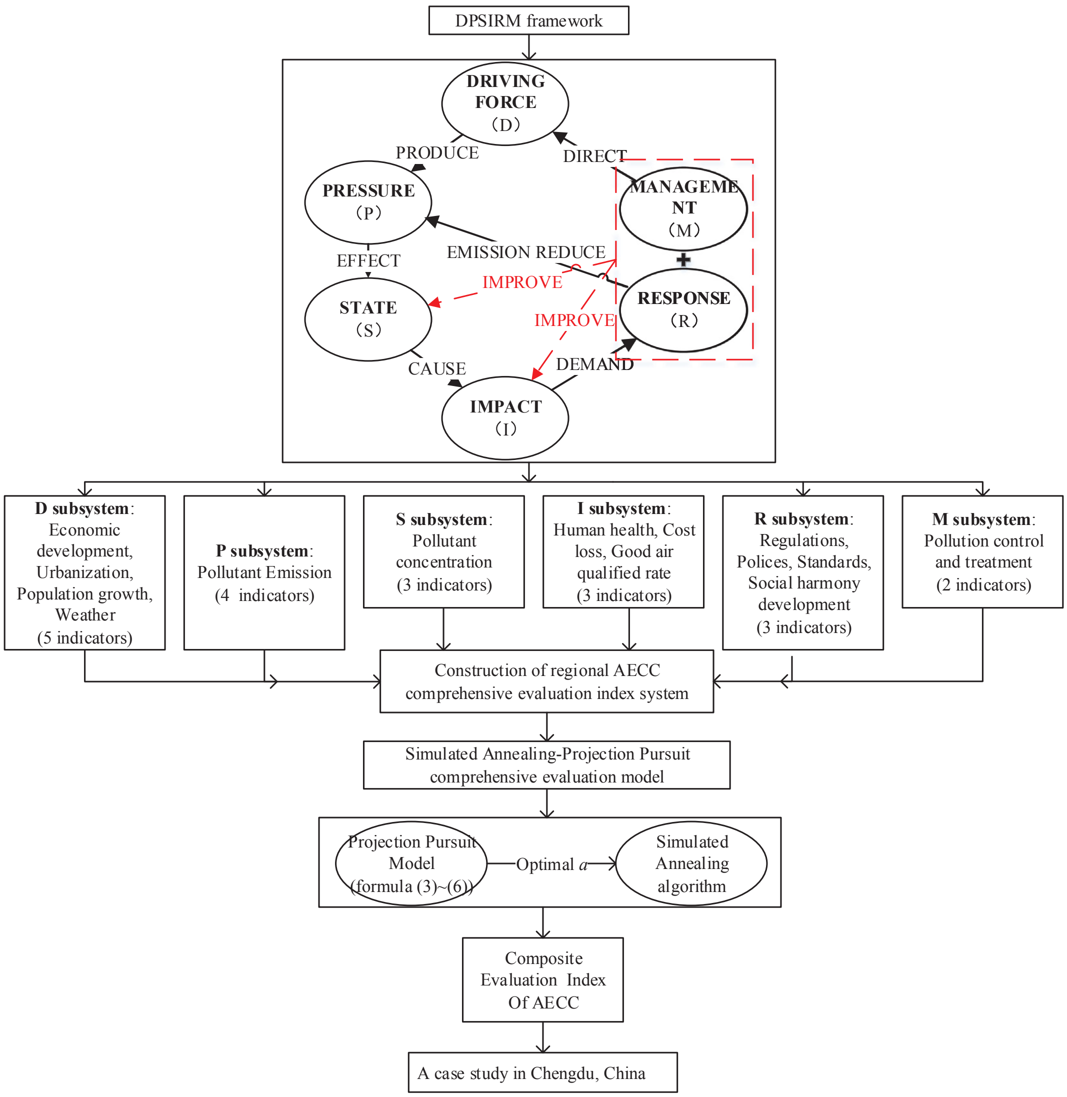

Fig. 1. Research flow chart.

system. And it describes a causal chain of atmospheric environmental problems. This model is widely used in environmental assessment area (Westing, 1989; Zhang et al., 2015; Zhang et al. 2014).

Projection Pursuit (PP) model was built based on statistical theory. It doesn't need to specify the indicator weights in complex system. So, Projection Pursuit model result is objective (Soledad et al., 2015) and it is widely used in the evaluation of resource and environmental quality (Zhang and Dong, 2009). In our paper, Projection Pursuit model was introduced to evaluate the reginal AECC. Based on DPSIRM model, an evaluation index system was constructed. And Simulated Annealing (SA) algorithm was used to optimize the parameters in Projection Pursuit model. By analyzing the projected characteristic value from different angles, relationships among the elements in evaluation index system were evaluated. Finally, this method was applied to evaluate of the regional AECC in Chengdu city. Our general methodology was showing in Fig. 1.

2. Material and methods

2.1. Studied area

As shown in Fig. 2, Chengdu is located in the western part of the Sichuan basin. It is one of the largest cities in the southwest of China. The Longquan mountain and the Qionglai mountain are located on the east and west side of the city. Because of the closed topographical condition, frequency of low wind speed in Chengdu is much higher. Therefore, atmospheric environmental problems in the city are very severe (Tao et al., 2013a,b).

Studies have revealed that the frequency of haze weather in Chengdu is the highest in four megacities of China (Beijing, Shanghai, Guangzhou, Chengdu). And this situation is getting worse year by year (Dai et al., 2013). As shown in Fig. 3, air quality in Chengdu decreased dramatically after 2011. Except for SO_2, the annual average pollutant concentration showed an upward trend. 2013 was the worst year and there were only 139 days air quality reached the second level of the ambient air quality standard (GB3095-2012).

2.2. Data sources

Data in our article was from Chengdu Statistical Yearbooks (Chengdu(China) Municipal Bureau of Statistics, 2007–2016) and the China Environment Yearbook (Environmental Statistical Department of China's National Bureau of Statistics, 2007–2016).

2.3. DPSIRM model

DPSIRM framework was shown in Fig. 4. Regional AECC index system based on DPSIRM model included 6 parts: Driving force