Physics and Chemistry of the Earth xxx (2017) 1–9

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

The study on ecological sustainable development in Chengdu

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ARTICLE INFO

Article history:
Received 23 May 2016
Received in revised form
10 February 2017
Accepted 2 March 2017
Available online xxx

Keywords:
Ecological footprint
STELLA
Ecological sustainable development
System dynamics
Chengdu

ABSTRACT

Ecological footprint is one of the important methods to study ecological sustainable development, but ecological footprint focuses on only the static calculation of ecological sustainable development and cannot dynamically predict its development. In this study, we combine ecological footprint with system dynamics software STELLA to construct a predictable model of ecological sustainable development. We introduce rate1 and rate2 into the model, which reflects the change in per capita consumption of biological resources and energy due to the socio-economic development, and by changing the values of them to simulate a variety of scenarios. The results show that ecological sustainable development of Chengdu is in the state of ecological deficit, which is 1.43 million hm^2 in 2013, and different rate1 and rate2 will lead to different changes in the ecological deficit. When rate1 = rate2 = 0.1, the degree of ecological deficit in Chengdu is reduced from 1.43 million hm^2 to 1.24 million hm^2 in 2013–2018, and after 2018, it begins to increase, which will reach 1.32 million hm^2 in 2021. And when rate1 = rate2 = 0.05, the ecological deficit of Chengdu in 2013–2021 will decrease gradually, which from 1.43 million hm^2 to 1.31 million hm^2. These results reflect the impact of economic development on ecological sustainable development, and it can provide a reference for the balanced development of economic and ecological protection, which will help decision makers to do something for ecological sustainable development planning of Chengdu.

1. Introduction

Environment protection and sustainable development are the main hotspots at present (Deng et al., 2016). The concept of sustainable development is commonly traced to the 'Bruntland Report' in 1987 (Harlow et al., 2013; Redclift, 2005), and since then more and more people put their eyes on research of ecological sustainable development (Verba and Ivanov, 2015). In the process of development, the city is facing a lot of risks, many scholars began to study how to realize ecological sustainable development of the city in order to solve these risks (Campbell, 1996; Chiesura, 2004; Deng and Bai, 2014). Many methods have been used to study ecological sustainable development of a city, e.g., ecological network analysis (Zhang et al., 2010), carbon footprint (Ramaswami et al., 2012), and energy analysis (Olaofe and Folly, 2013; Vollaro et al., 2014), which provide a great reference for the study of ecological sustainable development. But some experts consider ecological footprint as a better method for analyzing sustainable development (Coote, 2006; Du et al., 2006; Ferng, 2014; Li and Hou, 2011; Moffatt, 2000).

The ecological footprint is a method that measures natural capital demand of human beings by evaluating the area of ecological productive land which is needed to meet the consumption pattern (Wackernagel et al., 1999). The ecological footprint was put forward by Rees (1995), which was then improved by Wackernagel and Rees (1997). The ecological footprint reveals the relationship between the regional supply and demand of natural capital. It can make judgments on regional sustainable development by comparing human demand for natural capital and nature of renewable ability. The ecological footprint is also vividly likened to a footprint on the earth by a giant foot which is loaded with human and the things created by human, e.g., city and factory (Haberl et al., 2001). When the earth cannot bear such a large footprint, it is not sustainable and is likely to collapse (Li et al., 2016). Having a scientific theoretical basis clear conceptual framework (Bicknell et al., 1998) and a unified streamline index system (Kitzes et al., 2009; Wang and Gao, 2002), the ecological footprint has been widely accepted by many experts and scholars,

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http://dx.doi.org/10.1016/j.pce.2017.03.002
1474-7065/

and now it has become a very popular determination method for quantification of ecological sustainable development (Rees and Wackernagel, 1996).

The traditional ecological footprint model can only calculate ecological footprint of past time and cannot predict the future ecological sustainable development. Many scholars have therefore turned their attention to the predictable model of ecological footprint (Ferng, 2014; Kitzes and Wackernagel, 2009). For example, they constructed ecological sustainable development forecasting model by combining the ecological footprint with gray prediction (Gao and Xu, 2014), virtual ecological footprint (Wei et al., 2013), system dynamics (Jin et al., 2009), Artificial Neural Network (ANN) and CA-Markov (Wang et al., 2014). These methods point out the direction for dynamic prediction of ecological sustainable development, but little attention has been given to the effects of socio-economic development and population change. So our study aims to use the system dynamics method to construct ecological sustainable development forecasting model, which includes the socio-economic factors.

System Dynamics (SD) is a method based on the system theory, which is an important branch of system science and management science (Xia, 2009). Compared with other methods (gray prediction, virtual ecological footprint, ANN and CA-Markov), it can grasp the complex and nonlinear feedback of system, and make a good prediction (Rashedi and Hegazy, 2016). Also, it can solve the problem of simultaneity (mutual causation) by updating all variables in small time increments with positive and negative feedbacks and time delays structuring the interactions and control. And the most prominent advantage of it is to deal with the problem of high order, nonlinear, multiple feedback complex time-varying systems. STELLA is a system software based on the system dynamics theory (Costanza and Voinov, 2001), and it can predict the development of systems very well by setting different parameters in the dynamic prediction (Wang and Zhu, 2007). The application of STELLA software can be a good solution to the existing problems in the current ecological footprint model, but few scholars have combined them up to now.

Chengdu is an important central city in China, which plays an important role in the western development strategy and “the Belt and Road Initiatives” (Taylor, 2014), and it is of great theoretical and practical significance to carry out the comprehensive evaluation of ecological sustainable development capacity in Chengdu. With Chengdu as the study area, this study combined the ecological footprint with the STELLA software to study ecological sustainable development. This study constructed a SD model of ecological footprint, which regards socio-economic development and people's living standards as impact parameter, to analyze and forecast ecological sustainable development of Chengdu.

2. Study area and data

2.1. Study area

Chengdu is located between 102°54′E-104°53′E and 30°05′N-31°26′N, in the hinterland of the Chengdu Plain in the western part of Sichuan Basin (Fig. 1). Chengdu is one of the most historically important cities in China. It is the capital city of Sichuan province, serving as a provincial political, industrial and cultural center and a major economic center for southwest China (Qin, 2015). It has a sub-tropical climate, with the annual average temperatures of 15–18 °C, annual accumulated temperature above 10 °C of 4500–5700 °C, annual precipitation of about 1000 mm, and a non-frost period of 240-300 d. The annual sunshine hour is only 1000–1600 h in Chengdu, which is one of the lowest value in China (Zheng et al., 2010). Additionally, this region is an important ecological buffer zone in the upper reaches of Yangtze River Basin, which has a certain impact on ecological balance of the Yangtze River Basin (Peng et al., 2016).

Chengdu is a typical mega city with an area of approximately 1.21×10^4 km^2, which has 9 districts, 6 counties, and 4 county-level cities (Chen et al., 2016). The population of Chengdu was 11.88 million, and its GDP was 910.89 billion Yuan in 2013, which ranked third in the sub provincial cities, second only to Guangzhou and Shenzhen. There is complex topography, diverse natural ecological environment and rich biological resources and mineral resources in Chengdu. However, associated rapid increases in resource consumption have caused resources inefficiencies (Zhang et al., 2014). The conflict between economic development and environmental protection in Chengdu has become severe (Peng et al., 2016). Thus, it is of significant theoretical and practical interest to choose Chengdu as the study area.

2.2. Data

Based on the traditional ecological footprint, this study added the socio-economic development and people's living standards data to make the model more accurate. The data used in this study can be categorized into four parts, i.e., land use data, biological resource consumption data, energy consumption data, population and economic development data of Chengdu. Except for land use data, all of these data can been found in the statistical yearbook of Chengdu in 2006–2014. The biological resource consumption data, energy consumption data, population data and economic development data was shown in Table 1.

The land use data were extracted on the basis of the Landsat TM/ETM images covering Chengdu city in 2005, 2009 and 2013, which were downloaded from the website of United States Geological Survey (USGS) (Table 2). In this study, the method of human-computer interaction interpretation in ENVI software was used to interpret these remote sensing images. The land use of Chengdu was divided into five categories, i.e., farmland, forest land, grassland, water area and construction land (Fig. 2). Finally, the spatial analysis tool and mathematical statistics tool in ArcGIS were used to get the land use change of transition probability matrix.

In this part, it is worth noting that the original land use transfer matrix in this study is based on the land use data of 2005–2009, and we combined it with the land use data in 2009 to get the land use data of 2013 in Chengdu, which has slight difference with the real remote sensing data. It can be seen from the following table that the error in every land use type is less than 2% (Table 3). Since the difference of land use transfer matrix prediction is small, the land use data of Chengdu in 2009 and 2013 can be used to get the new transfer matrix and predict the land use data during 2013–2017 and 2017–2021.

3. Methodology

3.1. Calculation model of ecological footprint

Ecological footprint can be divided into two parts, the supply of ecological footprint and the demand of ecological footprint. The supply of ecological footprint also can be seen as ecological carrying capacity, which usually refers to the maximum population that can be carried for an organism, given a certain quantity of food, habitat, water and other life infrastructure present (Rees, 1996; Xu et al., 2010). And in this paper, it means the maximum area of productive land that Chengdu can provide. The demand of ecological footprint in this paper means the productive land area needed by the whole population in Chengdu under the certain living standard.

The supply of ecological footprint was calculated as follows.

Please cite this article in press as: Li, Y., et al., The study on ecological sustainable development in Chengdu, Physics and Chemistry of the Earth (2017), http://dx.doi.org/10.1016/j.pce.2017.03.002