Ecological Indicators 96 (2019) 270–277

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Tracing the spatial variation and value change of ecosystem services in Yellow River Delta, China

Chengdong Wang[a], Xiao Li[c], Huajun Yu[a], Yutao Wang[a,b,*]

[a] Fudan Tyndall Center and Shanghai Key Laboratory of Atmospheric Particle Pollution and Prevention (LAP[3]), Department of Environmental Science & Engineering, Fudan University, Shanghai 200438, China
[b] Institute of Eco-Chongming (SIEC), No. 3663 Northern Zhongshan Road, Shanghai 200062, China
[c] Center for Industrial Ecology, School of Forestry and Environmental Studies, Yale University, 195 Prospect St, New Haven, CT 06511, USA

ARTICLE INFO

Keywords:
Dongying
Ecosystem services
Ecological compensation
Emergy analysis
Urbanization

ABSTRACT

Land-use change driven by urbanization influences the supply of ecosystem services, which are vital for regional economy and sustainable development. Tracing the spatial variation and value change of ecosystem services in rapidly urbanized areas can provide important planning and policy suggestions to achieve ecologically-sound regional development. In this study, Emergy analysis was used to conduct a regional assessment of ecosystem services in the Yellow River Delta (YRD), China, from 2009 to 2015. The quantity, emergy, and economic values of indirect ecosystem services in YRD were calculated. The results of this study indicate that the expansion of built-up land in the process of urbanization has caused regional landscape fragmentation and the loss of ecological land such as grassland. The emergy value of ecosystem services was reduced by 10.89%, quantitatively revealing the extent to which the ecosystem services were adversely affected in the course of urbanization. Moreover, ecosystem services became scarcer, leading to a rise in their economic value. This value increase of ecosystem services at the macro level should be taken into account in the formulation of ecological compensation standards. Spatial visualization analysis was further performed to demonstrate the geographical distribution of ecosystems services. Our findings provide useful information for the protection of ecosystem services and the enhancement of regional sustainability.

1. Introduction

The process of urbanization is rapid in China, especially during past decades (Li et al., 2018). The rapid expansion of cities on the one hand has promoted the development of the local social economy, but it has also caused negative impacts on local environment. Regional ecosystem suffered huge pressure accompanied with social-economic development, which provide huge supports through ecosystem services including both the material as well as non-material benefits for human society (Small et al., 2017). Ecosystem services refer to the direct or indirect benefits that ecosystems and ecological processes provide for humans. Ecosystems and ecological processes serve as a vehicle for ecosystem service functions. They are linked through material circulation, energy flow, and information transfer, and provide the necessary environmental conditions and material basis for human society (Costanza et al., 1997; Daily, 1997).

People have long been aware of the importance of the natural environment and natural resources. The concept of ecosystems was proposed by Tansley in the 1930s, using the scientific approach to the concepts, components, structure types, and service functions of ecosystems (Tansley, 1935). Research on evolution and other aspects has increased, greatly enriching the content and application of ecology, and gradually developed into a discipline system in the 1960s (Helliwell, 1969; King, 1966). Odum et al. (1971) further discussed the definition of ecosystems and their composition and functions. The concept of ecosystem services was gradually proposed with the deepening of related research. The definition of ecosystem services has been continuously improved by many ecologists (Ehrlich and Ehrlich, 1981; Gordon, 1992). The most representative studies are the monographs on ecosystem services published by Daily (1997) and the academic papers on the valuation of global ecosystem services issued by Costanza et al. (1997) in the same year. Daily (1997) described ecosystem services as the conditions and processes that natural ecosystems and their species provide to supply and maintain human survival, and human understanding of ecosystem services and related research progress are also described in detail. Costanza et al. (1997) suggested that ecosystem

* Corresponding author at: Department of Environmental Science & Engineering, Fudan University, Shanghai 200438, China.
E-mail address: yutaowang@fudan.edu.cn (Y. Wang).

https://doi.org/10.1016/j.ecolind.2018.09.015
Received 9 July 2018; Received in revised form 28 August 2018; Accepted 7 September 2018

services provide human society with food, raw materials, and other ecosystem products, as well as climate regulation, soil and water conservation, and other services. Thus, ecosystem services can include benefits such as products and services that humans directly or indirectly obtain from ecosystems. According to the differences in products and services, ecosystem services were divided into 17 specific types, and value assessment methods were applied for the first time to global ecosystems (Costanza et al., 1997). De Groot et al. (2002) believes that ecosystem products, functions, and services were closely linked together. Ecosystem services refer to the ability of ecosystems to directly or indirectly provide services to human society. The definition of ecosystem service function proposed in Millennium Ecosystem Assessment (MA) refers to the human benefits from the natural ecosystem, and it has formally summarized types of ecosystem services into four major categories: provisioning service, regulating service, cultural service, and supporting service. This report has been widely recognized and applied by scholars, and most of the follow-up research on ecosystem service evaluation adopts the classification framework proposed in MA (2003).

The valuation of ecosystem services can provide a scientific reference for the construction of a regional sustainable development evaluation system. Fons et al. (2018) studied the forest ecosystem functions of Europe and found large potential of forest multifunctionality waiting to be developed. Pueffel et al. (2018) assessed the ecosystem service of brownfields of urban green space and the results showed a particular role was played in ecosystem service by brownfields which is different from formal urban green spaces. Through the assessment of the value of ecosystem services, quantitative accounting of products directly or indirectly provided by ecosystems (such as food) and services (such as carbon fixation and oxygen release) improve understanding of the value of ecosystem services.

The assessment of ecosystem services can measure the contribution of ecosystems to humans and the benefits that human society obtained from ecosystems. The traditional assessment methods mainly include material quantity evaluation and monetary value evaluation. They have their own advantages and disadvantages. The quantity evaluation method can measure the quantity of services more accurately, but it does not reflect its importance to humans. The monetary value method can reflect 'people's willingness to pay for the ecosystem service, and thus provide reference for setting ecological compensation standards (Wang et al., 2017; Wang et al., 2018). It is difficult, however, to truly reflect the importance of some ecosystem services that are not scarce with this method. In addition to the above two methods, the current evaluation approach includes emergy analysis, non-monetary evaluation, and dynamic modeling evaluation. By using the emergy analysis, the quantity of regional ecosystem services can be converted into emergy values, and then analyzed and compared. The economic value of ecosystem services can be accounted by combining economic data such as GDP of the study area. Since the metadata of the emergy analysis and the GDP economic data are specific for the research area, the evaluation results are more targeted, reflecting the real situation more objectively.

In this study, emergy theory was combined in evaluation of ecosystem service and the results visualized by ArcGIS. This study take Dongying, the core city of the Yellow River Delta High Efficient Ecological Economic Zone, as the research object. The "Development Plan for the Efficient Ecological Economic Zone of the Yellow River Delta" was formally approved by the State Council in 2009. The development of the Yellow River Delta (YRD) region has become a national strategy. The core cities of the eco-economic zone are driven by regional development planning and the socio-economic development is rapid. The starting year for the study was 2009 and 2015 was selected as the comparative year, according to data availability. Firstly, the remote sensing image data were used to analyze the land use changes of the study area in 2009 and 2015. Emergy analysis and ecosystem service assessment of core city's ecosystems were conducted based on the socio-economic data of 2009 and 2015 and remote sensing data. Using emergy theory and socio-economic-natural complex ecosystem theory, the natural subsystem and socio-economic subsystem of the study area were organically combined through emergy accounting (Wang et al., 2011). In order to understand the value of regional ecosystem services and the changes in ecosystem services during urbanization, this study examined and compared ecosystem service according to different land-use types and analyzed the changes during regional urbanization. The results of this research can provide reference for reasonable urban planning, protection and utilization of ecosystem services, and formulation of ecological compensation standards.

2. Methodology

2.1. Study area

The Yellow River Delta is one of the three major estuary deltas in China owing abundant natural resources. In the Yellow River estuary in the northeast of the Yellow River Delta, a large area of new land is formed around the estuary each year due to the deposition of a large amount of river sediments brought by the Yellow River (Wang et al., 2016; Xiang et al., 2010). The large-scale terrestrial and aquatic ecosystems created by the Yellow River form a temperate estuarine wetland ecosystem. However, the phenomenon of land salinization is common on this newly formed land due to land–sea interactions in areas close to the sea inlet (Künzer et al., 2014). Because of the effects of soil salinity disturbance, the landscape of terrestrial ecosystems in the region is characterized by different types of vegetation patches dominated by bushes (Jiao et al., 2014; Zhang et al., 2013).

The "Development Plan for High-efficiency Ecological Economic Zone in the Yellow River Delta" serves as a national development policy. According to the development principles clearly stated in the policy, the development and utilization of the Yellow River Delta need to prioritize ecological environmental protection. Moreover, the ecological environment of the basins of the Lower Bohai Bay and Yellow River should be protected and maintained. The Yellow River Delta Efficient Ecological Economic Zone is China's first and largest ecological economic zone at the national level. Dongying is the core city of the Yellow River Delta Efficient Ecological Economic Zone and is the main area for local governments to carry out economic construction and land development and utilization. At present, under the background of urbanization, the land use in Yellow River Delta has changed rapidly. Moreover, socio-economic development has increased frequency of human activities in the area, which has inevitably exerted tremendous pressure on the local natural environment and has had a direct impact on regional ecosystem services. For these reasons, Dongying was selected as the study area. In addition, Dongying is not only the core area of the highly efficient ecological economic zone of the Yellow River Delta, but also an important oil industry base. China's important Shengli Oilfield is located here. As the region is rich in petroleum, industrial activities such as oil exploration and mining have also had a huge impact on the local ecological environment (Ottinger et al., 2013). The administrative jurisdiction of Dongying includes three districts (Dongying, Hekou, and Kenli) and two counties (Guangrao and Lijin). It encompasses not only urban areas (built-up areas) but also a large number of non-urban areas and undeveloped areas such as rural areas and townships, which contains rich natural ecosystems. Therefore, the statistical data in this study were also based on Dongying's administrative jurisdiction for analysis and accounting.

2.2. Emergy analysis

The emergy theory and method was first proposed by H.T. Odum. Odum defined emergy as the total amount of effective energy that a direct investment or indirect investment in a product or service as it takes shape (Odum, 1996). Solar energy is one of the primary energy