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

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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

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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
Available online 12 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 multi-functionality 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 sources driving natural ecosystem processes and socio-economic activities, besides tides and earth heat. Therefore, by using solar energy as a unit of unity energy, various forms of matter and energy can be converted into solar equivalents by a certain conversion factor (known as transformity), so that further operations and comparisons become feasible. The transformity was calculated according to the emergy baseline. Emergy driving the biosphere was evaluated as 9.44E+24 seJ/year at first according to Odum (1996), and then updated to 15.83E+24 seJ/year (Brown and Ulgiati, 2004; Odum et al., 2000). In this study, we carried out emergy analysis on YRD's social-economic-natural complex ecosystem in 2009 and 2015, and further calculated the emergy/money ratio (EMR) with GDP data (Wang et al., 2016). All transformities applied in this study were calculated under the baseline of 15.83E+24 seJ/year.

2.3. Ecosystem services

The total value of ecosystem services is equal to the sum of the values of various different ecosystem services within the study area. Because of the complexity of the ecosystem itself, as well as the human understanding constraints of the ecosystem services, the framework of ecosystem service evaluation is not yet unified (Costanza et al., 2017). The proportion of direct services is generally not high, and its value can generally be reflected in the market. The values of direct services such as timber production and food supply can be reflected in the market, so direct services were not included in this study. Here we focused on indirect services related to the improvement of the ecological environment. It is often difficult to measure the economic values of these services directly, and many methods and models have been applied to study these (Turner et al., 2016). In this study, Emergy analysis was employed to evaluate the quantity, emergy value, and economic value of ecosystem services. Spatial analysis was used for the visualization of ecosystem services. As mentioned before, the economic value of direct services is reflected on the market. The value of cultural services, such as access and aesthetic value, is usually obtained directly from statistical data such as regional tourism income, which is not suitable for spatial visualization analysis. The framework of ecosystem service evaluation in this study was developed as shown in Table 1. The carbon fixation, oxygen release, soil conservation, nutrient retention, and water conservation were evaluated and visualized in this study, given that they are the main ecosystem services in this area.

2.3.1. Carbon fixation service

The gas regulation ecosystem service mainly manifests as the process of carbon fixation and oxygen release, through which photosynthesis by plants absorbs CO_2 from the atmosphere to synthesize organic matter and releases O_2. The process of carbon sequestration and oxygen release in ecosystems is very important for global and regional carbon cycle research. According to the assessment report of the Intergovernmental Panel on Climate Change (IPCC), the large amount of greenhouse gas emissions in the atmosphere such as CO_2 is the main cause of global climate change (Solomon, 2007). According to the formula of plant photosynthesis and respiration, primary producer like the plant needs to absorb 1.63 g CO_2 per 1 g of dry matter produced. In this study, the amount of NPP in the study area obtained by remote sensing interpretation in 2009 and 2015, respectively, and the amount of fixed CO_2 was calculated as follows:

$$Q_{CO_2} = \mathrm{NPP} \times 1.63 \times A \tag{1}$$

where Q_{CO_2} is the quantity of fixed CO_2 in t, NPP is annual net primary productivity in t/km^2, and A is the area of the study area in km^2.

According to the CO_2 fixed material quantity accounting results, the emergy equivalent of the carbon sequestration service was calculated as follows:

$$Em_{CO_2} = Q_{CO_2} \times T_{co_2} \tag{2}$$

where Em_{CO_2} is the emergy value of the fixed CO_2 in the ecosystem in sej; Q_{CO_2} is the material quantity of the fixed CO_2 in the ecosystem in t; and T_{co_2} is the emergy transformity of CO_2, which is 3.78E+07 sej/g (Li et al., 2005).

The monetary value of the carbon sequestration service was calculated based on the EMR in 2009 and 2015 as follows:

$$Em\$_{CO_2} = Em_{CO_2}/\mathrm{EMR} \tag{3}$$

where $Em\$_{CO_2}$ is the emergy monetary value of the carbon sequestration service in \$, Em_{CO_2} is the emergy value of the carbon sequestration service in sej, and EMR is the emergy/money ratio of the study area in sej/\$. The monetary value of the carbon sequestration services in 2009 and 2015 were calculated according to the above calculation formula and the results were visualized in ArcGIS 10.2 (Environmental Systems Research Institute, California, USA).

2.3.2. Oxygen release service

In the ecosystem, vegetation also releases O_2 while synthesizing organic matter through photosynthesis. O_2 is the most basic substance for maintaining normal life activities such as humans and animals and plants. According to the equation of plant photosynthesis and respiration, we know that 1.19 g O_2 is released per 1 g of dry matter produced. Based on the data of NPP mass of regional ecosystem obtained by remote sensing interpretation, the amount of O_2 released were calculated for 2009 and 2015 as follows:

$$Q_{O_2} = \mathrm{NPP} \times 1.19 \times A \tag{4}$$

where Q_{O_2} is the mass of fixed O_2 in t, NPP is annual net primary productivity in t/km^2, and A is the area of the region in km^2.

The emergy equivalent of the oxygen release service was calculated based on the calculated oxygen release service. The formula is as follows:

$$Em_{O_2} = Q_{O_2} \times T_{o_2} \tag{5}$$

where Em_{O_2} is the emergy value of O_2 released by the ecosystem in sej, Q_{O_2} is the material quantity of the fixed O_2 of the ecosystem in t, and T_{o_2} is the emergy transformity of O_2, which is 5.11E+07 sej/g (Li et al., 2005).

The monetary value of the oxygen release service was calculated separately in combination with the EMR for 2009 and 2015. The formula is as follows:

$$Em\$_{O_2} = Em_{O_2}/\mathrm{EMR} \tag{6}$$

where $Em\$_{O_2}$ is the emergy monetary value of the oxygen release service in \$, Em_{O_2} is the emergy value of the oxygen release service in sej, and EMR is the emergy/money ratio of the study area in sej/\$.

2.3.3. Soil retention

Soil loss is one of the major environmental issues facing society. The continuous expansion of human activities leads to the destruction of the original vegetation cover on the soil, leaving soil exposed to erosion by precipitation and wind. The amount of the erosion is far greater than the amount of new soil created by the parent material layer. As a result, the soil layer in the area is continuously reduced and nutrients in the soil are lost, eventually leading to barren land and associated ecological problems. In this study, the soil conservation assessment was conducted

Table 1
The framework of the YRD's ecosystem service evaluation.

Item	Ecosystem service	Evaluation index	Data source
1	Carbon fixation service	CO_2 fixation	NPP
2	Oxygen release service	O_2 release	NPP
3	Soil conservation	Soil retention	Soil retention
4	Nutrient conservation	N, P, K conservation	Soil retention
5	Water conservation	Water conservation	Water conservation

using the Universal Soil Loss Equation (USLE) model proposed by the U.S. Department of Agriculture as follows:

$$Q_{soil} = R \times K \times L \times S \times C \times P \quad (7)$$

where Q_{soil} is the annual average amount of soil erosion in t/km^2, R is the precipitation erosion factor in MJ mm hm^{-2} h^{-1} a^{-1}; K is the soil erodibility factor, the unit is t hm^{-2} h MJ^{-1} mm^{-1} hm^{-2}; L is the slope length factor, dimensionless; S is the slope factor, dimensionless; C is the surface vegetation cover and management factor, dimensionless; and P is the soil conservation factor, dimensionless.

Based on the results of soil conservation quantity, the emergy analysis of the YRD's soil maintenance service was calculated as follows:

$$Em_{soil} = Q_{soil} \times \mu \times T_{soil} \quad (8)$$

where Em_{soil} is the emergy value of the soil maintenance service in sej; Q_{soil} is the soil-maintained substance quantity in t; μ is the top soil energy conversion ratio, with a value of 6.78E+02 J; and T_{soil} is the emergy transformity for soil conservation services, which is 7.4E+04 sej/J(Kangas, 2002).

The monetary value of the soil maintenance service was calculated from the EMR in 2009 and 2015 from the emergy analysis results as follows:

$$Em\$_{soil} = Em_{soil}/\mathrm{EMR} \quad (9)$$

where $Em\$_{soil}$ is the emergy monetary value of soil maintenance service in \$, Em_{soil} is the emergy value of soil maintenance service in sej, and EMR is the emergy/money ratio of the study area in sej/\$.

2.3.4. Nutrient retention

Nutrients in soils are important for plant growth. In addition to reducing soil erosion, soil conservation services also retain nutrients in the soil. In this study, three kinds of nutrients were evaluated: N, P and K. The N, P and K digital data were obtained from the Soil Science Data Center (http://soil.geodata.cn/). After the projection transformation, the N, P and K spatial distribution data (1 km spatial resolution) for the study area were extracted and analyzed. Based on the soil conservation data, the masses of N, P and K were calculated as follows:

$$Q_j = Q \times \omega_j \quad (10)$$

where Q_j is the mass of jth nutrient content in g, Q is the amount of Soil conservation in t, and ω_j is the jth soil nutrient content in g/t. The calculation and visual analysis of the N, P, K nutrient retention service was achieved through ArcGIS.

Based on the calculation results of N, P and K nutrients for three nutrients, the emergy value of nutrient retention service was calculated as follows:

$$Em_{NPK} = \sum_{1}^{j} Q_j \times T_j \quad (11)$$

where Em_{NPK} is the emergy value of nutrient maintenance in sej; Q_j is the material quantity of the jth nutrient in g; and T_j is the emergy transformity of the jth nutrient in sej/g, where T_N is 4.62E+09 sej/g; T_P is 6.88E+09 sej/g; T_K is 2.96E+09 sej/g (Yan and Odum, 2000). Using the ArcGIS geographic information system, the emergies of N, P and K nutrients were calculated, and the emergy value of the nutrient retention service was obtained through overlay analysis.

The monetary value of the nutrient retention service was calculated based on the EMR in 2009 and 2015 in the emergy analysis results. The formula is as follows:

$$Em\$_{NPK} = Em_{NPK}/\mathrm{EMR} \quad (12)$$

where $Em\$_{NPK}$ is the emergy monetary value of nutrient retention service in \$, $Em_{NPK}$is the emergy value of nutrient retention service in sej, and EMR is the emergy/money ratio of the study area in sej/\$.

2.3.5. Water conservation

The demand for water resources is increasing with the expansion of urbanization and economic development. The shortage of water resources and the deterioration of water quantity have attracted the attention of many scholars (Rodell et al., 2018). Regional ecosystems can conserve precipitation, regulate runoff, and purify water through water conservation thus playing an important role in the regional water cycle. The water balance method has advantages in water conservation assessment, such as ease of operation and accurate evaluation results (Liu et al., 2016). The main principle of this method is to consider the study area as a whole. Precipitation is water input and evapotranspiration is water output. The difference is the amount of water conservation in this area. The water balance method was used in this study to estimate the YRD's water conservation capacity. The calculation formula is as follows:

$$Q_w = (P - ET) \times A \quad (13)$$

where Q_w is the water conservation capacity of the study area in m^3 and P is the annual precipitation in the study area in mm. Annual precipitation in YRD in 2009 and 2015 was 634.1 and 684.7 mm, respectively, according to the YRD's Statistical Yearbook for 2010 and 2016. ET is the annual evapotranspiration in the study area in mm. Annual evapotranspiration data from YRD were obtained from Mod16A3 provided by NASA. After projection transformation and extraction analysis, Mod16A3 digital data were exported to TIFF format. After processing, annual evapotranspiration data were obtained for 2009 and 2015 at 1 km spatial resolution. Finally, A is the area of the region in km^2. Water conservation quantity accounting and visual analysis were achieved using the Map Algebra Tool in ArcGIS.

According to the results of water conservation, the emergy conservation services were analyzed for YRD in 2009 and 2015. The formula is as follows:

$$Em_w = Q_w \times \rho \times G \times T_w \quad (14)$$

where Em_w is the total emergy value of the water source in the study area in sej; Q_w is the water source conservation amount in the study area in m^3; ρ is the density of water, and the value is 1.0E+06 g/m^3; G is Gibbs free energy, and the value is 4.94 J/g; and T_w is the emergy transformity of water resources. Chen et al. (2006) calculated the emergy transformity of water resources to be 3.63E+04 and 4.55E+04 sej/J for surface water and groundwater, respectively. In the current study, the mean value of the two values (4.09E+04 sej/J) was taken as the emergy transformity of the water conservation service in the emergy analysis. The spatial analysis of map algebra tools was used in ArcGIS to account for and visually analyze the emergy values of the water conservation services in 2009 and 2015.

The monetary values of water conservation services were calculated based on the EMR in 2009 and 2015 in the emergy analysis results. The formula is as follows:

$$Em\$_w = Em_w/\mathrm{EMR} \quad (15)$$

where $Em\$_w$ is the emergy monetary value of water conservation services in \$; Em_w is the emergy value of water conservation services in sej, and EMR is the emergy/money ratio of the study area in sej/\$.

2.4. Landscape pattern

Under the background of urbanization development, land-use and land-cover change leads to considerable changes in landscape pattern as well as great impact on regional ecosystem services (Sutton et al., 2016). Therefore, the spatial pattern is very important in the evaluation of ecosystem services in the region. The landscape pattern usually includes the types, number, and spatial distribution of the constituent units in the study area (Dale and Fortin, 2014). The landscape structure plays a decisive role in the service function of the regional ecosystem and at the same time affects the future dynamic changes of the

Table 2
Quantity statistics for YRD's ecosystem services.

	Carbon fixation (g)	Oxygen release (g)	Soil conservation (g)	Nutrient retention (g)			Water conservation (g)
				N	P	K	
2009	2.83E+06	2.07E+06	1.91E+07	1.54E+10	1.98E+10	3.71E+11	1.68E+09
2015	2.58E+06	1.88E+06	1.54E+07	1.23E+10	1.55E+10	2.96E+11	2.52E+09

ecosystem service function in the region (Li and Wu, 2004).

In this study, we used the Landsat-5 remote sensing image in 2009 and the Landsat-8 remote sensing image in 2015 as basic data. The remote sensing image has a spatial resolution of 30 m. Through the supervised classification method, the land cover maps of YRD were obtained for 2009 and 2015. According to the climatic conditions in the study area, remote sensing images with good vegetation growth time in summer were selected to facilitate the extraction of vegetation information in artificial visual interpretation. Through remote sensing image processing software ENVI 5.1, pre-processing, cropping, and supervised classification of remote sensing images in the study area were conducted to obtain land use maps for YRD in 2009 and 2015.

In order to ensure the accuracy of the classification results, we visited YRD many times during 2013–2015 to carry out investigations on the status of vegetation and land-use and obtained a large number of plant community data and field verification points. The verification points obtained after field inspections were used to correct the classification results of remote sensing images in 2015, thereby improving the accuracy of the classification. As the central and eastern region is located in the core area of the Yellow River Delta, a number of field surveys have found that the soil salinization was serious in this area. The main vegetation landscape features were *Tamarix sinensis* shrub, *Salix matsudana* forest, *Suaeda salsa* salty meadow, *Aeluropus littoralis* meadow, and *Phragmites communis* wetland, as well as farmland and large-area tidal flats. The lack of forests, sparse trees, and lush meadows were the main landscape features. Therefore, based on comprehensive consideration of the vegetation status of the study area and the resolution of remote sensing images, the land use types in the study area were divided into five categories: grassland, farmland, built-up land, water, and bare land.

3. Results

3.1. Quantity, emergy and economic value of ecosystem services

The quantity statistics of YRD's ecosystem services are shown in Table 2. Quantity of carbon fixation, oxygen release, soil conservation and nutrient retention were all decreased in 2015 compared with 2009. The results indicated that the ecosystem service function is declining. While quantity of water conservation was increased in 2015 compared with 2009. This is mainly due to the higher precipitation in 2015 than in 2009.

Emergy statistics of YRD's ecosystem services are shown in Table 3. Emergy of carbon fixation, oxygen release, soil conservation and nutrient retention were all decreased in 2015 compared with 2009 showing a decreasing trend consistent with quantity evaluation. While emergy of water conservation was increased by 1.69E+20 sej in 2015 compared with 2009.

Table 3
Emergy statistics for YRD's ecosystem services.

	Carbon fixation (sej)	Oxygen release (sej)	Soil conservation (sej)	Nutrient retention (sej)	Water conservation (sej)
2009	1.07E+20	1.06E+20	9.58E+20	1.31E+21	3.39E+20
2015	9.76E+19	9.63E+19	7.71E+20	1.04E+21	5.08E+20

Table 4
Economic value statistics of YRD's ecosystem services.

	Carbon fixation ($)	Oxygen release ($)	Soil conservation ($)	Nutrient retention ($)	Water conservation ($)
2009	2.36E+07	2.33E+07	2.11E+08	2.89E+08	7.49E+07
2015	2.49E+07	2.46E+07	1.97E+08	2.65E+08	1.30E+08

Economic value statistics (Em$) of YRD's ecosystem services are shown in Table 4. Economic values of carbon fixation, oxygen release and water conservation were increased in 2015 than 2009. While economic value of soil conservation and nutrient retention were decreased in 2015 than 2009.

3.2. Economic values of ecosystem services

With the layers of carbon sequestration service value, oxygen release service value, water conservation value, soil conservation value, and nutrient conservation value, overlay analyze tool was employed in ArcGIS to obtain the total Em$ value of the ecosystem service in the study area in 2009 and 2015 (Figs. 1 and 2, respectively).

The calculated results are shown in Table 5. In 2009, the total Em$ value of the ecosystem services was 6.22E+08$, and the total Em$ value of the ecosystem services in 2015 was 6.41E+08$. The average Em$ value across YRD increased by 2.85% in 2015 compared with 2009.

The total value of YRD ecosystem services in 2009 was 6.22E+08$, of which the value of carbon fixation and oxygen release was 4.69E+07$, accounting for 7.55%; the soil conservation value was 2.11E+08$, accounting for 33.93% the nutrient retention value was 2.89E+08$, accounting for 46.47%; and the water conservation value was 7.49E+07$, accounting for 12.05%. The total value of YRD ecosystem services in 2015 was 6.41E+08$, in which the value of carbon fixation and oxygen release was 4.95E+07$, accounting for 7.71%; the soil conservation value was 1.97E+08$, accounting for 30.71%; the nutrient retention value was 2.65E+08$, accounting for 41.32%; and the water conservation value was 1.30E+08$, accounting for 20.26% (Fig. 3).

4. Discussion

4.1. Emergy changes of YRD's ecosystem services

A comparative analysis of the emergy calculation results of YRD's ecosystem services in 2009 and 2015 is shown in Table 6. The emergy value of carbon fixation and oxygen release service in 2015 was 8.92% lower than that in 2009. This was mainly because of the reduction of the net primary productivity of the ecosystem from 1.73E+12 g C in 2009 to 1.57E+12 g C in 2015, resulting in a reduced emergy value of the carbon fixation and oxygen release ecosystem services. The emergy value of soil conservation services was reduced by 19.52% in 2015 compared with 2009. The main reason for soil erosion was the destruction of the original vegetation cover, which led to the erosion of the soil, and the reduction of soil conservation services reflected the

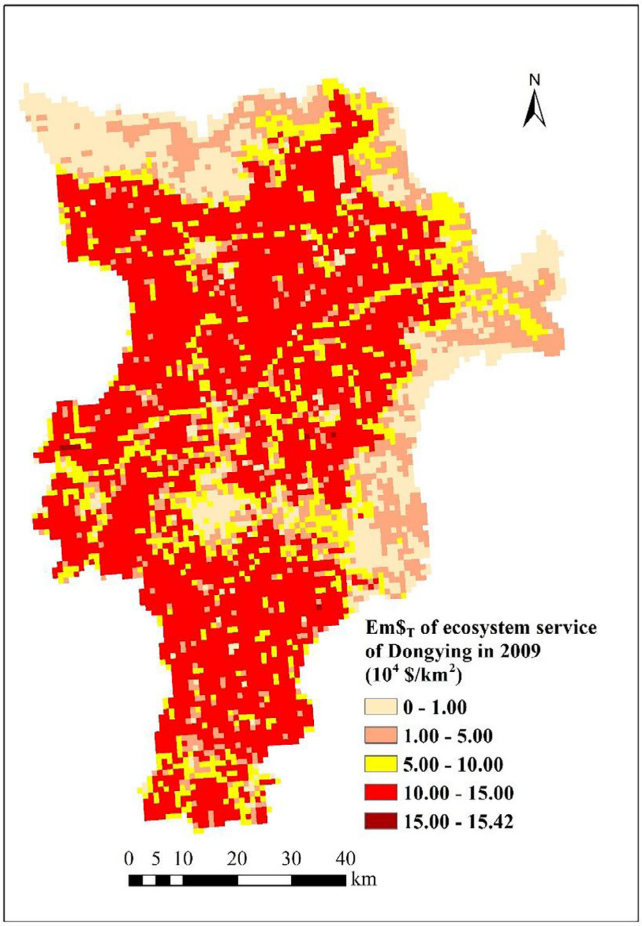

Fig. 1. Total economic value (Em$_T) of ecosystem services in YRD in 2009.

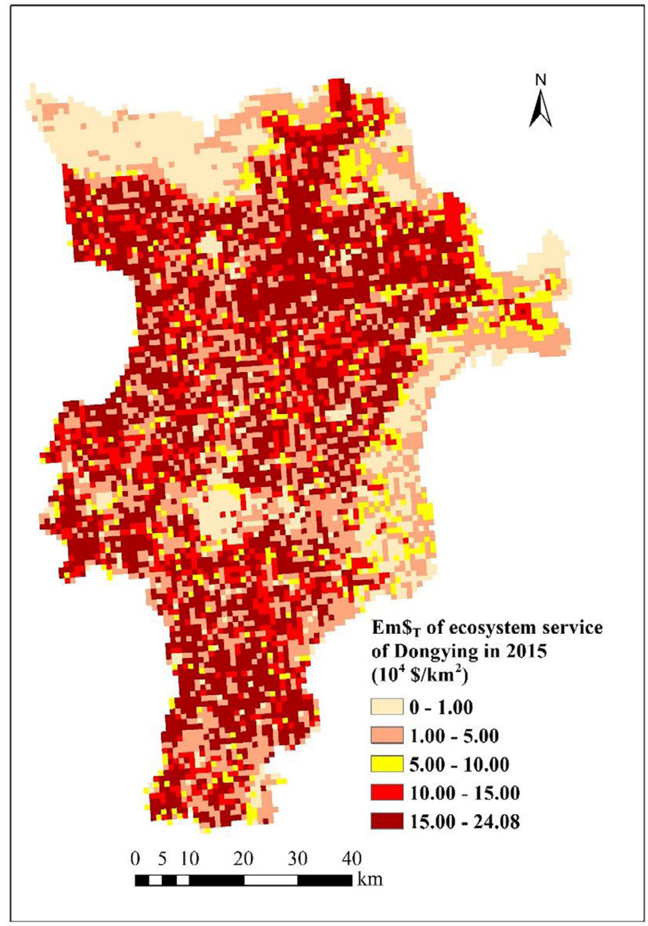

Fig. 2. Total economic value (Em$_T) of ecosystem services in YRD in 2015.

urbanization process in the central and eastern region. Large changes in land use and destruction of local ecosystems have affected soil conservation services. The emergy value of nutrient maintenance services decreased by 20.61% in 2015 compared with 2009. Soil loss is accompanied by the loss of nutrients such as N, P, and K. As a result, the reduction in soil conservation services also affected the soil fertility. The emergy value of water conservation services increased by 49.85% in 2015 compared with 2009. This was mainly because the annual precipitation was considerably higher than in 2009; the total emergy value of ecosystem services in 2015 was 10.89% lower than in 2009.

4.2. Em$_T$ *changes of YRD's ecosystem services*

Using the results of the various types of ecosystem service emergies calculated in Table 6, combined with the EMR for 2009 and 2015, the monetary values of the emergy values of the YRD's ecosystem services in 2009 and 2015 were calculated and analyzed. As shown in Table 7, the value of carbon fixation and oxygen release service increased by 5.54% in 2015 compared with 2009, the value of the soil conservation service in 2015 decreased by 6.64% compared with 2009, and the nutrient maintenance service decreased by 8.24% in 2015 compared with 2009. The energy value of water conservation services increased by 73.09% in 2015 compared with 2009 and the total energy value of ecosystem services in 2015 increased by 3.14% compared with 2009.

When measured by emergy, the YRD's ecosystem service in 2015 showed a downward trend compared with 2009. However, when the YRD's ecosystem service was converted to the economic value by combining the EMR for the year, the macroeconomic value of YRD's ecosystem services in 2015 showed an upward trend compared with

Table 5
Statistics of Em$ of ecosystem services in YRD.

Year	Total Em$ of ecosystem service			
	Min ($/km^2)	Max ($/km^2)	Mean ($/km^2)	Total ($)
2009	0	1.54E+05	8.06E+04	6.22E+08
2015	0	2.03E+05	8.29E+04	6.41E+08

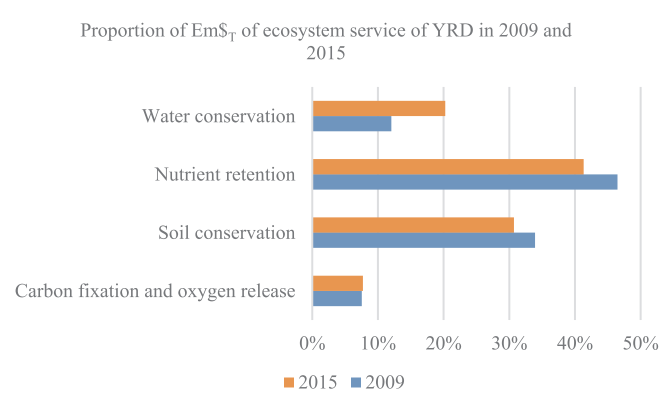

Fig. 3. Proportion of Em$_T of ecosystem service of YRD in 2009 and 2015.

2009. This was mainly because of the change in the EMR of YRD in 2009 and 2015. According to Odum (1996), the EMR is much lower in developed countries or regions than in developing countries or regions. This is because each unit of GDP produced in developing countries or

Table 6
Emergy changes of YRD's ecosystem services in 2009 and 2015.

	Carbon fixation and oxygen release (sej)	Soil conservation (sej)	Nutrient retention (sej)	Water conservation (sej)	Total (sej)
2009	2.13E+20	9.58E+20	1.31E+21	3.39E+20	2.82E+21
2015	1.94E+20	7.71E+20	1.04E+21	5.08E+20	2.51E+21
Change ratio	−8.92%	−19.52%	−20.61%	49.85%	−10.89%

Table 7
Em$\$_T$ changes of YRD's ecosystem services in 2009 and 2015.

	Carbon fixation and oxygen release ($)	Soil conservation ($)	Nutrient retention ($)	Water conservation ($)	Total ($)
2009	4.69E+07	2.11E+08	2.89E+08	7.49E+07	6.22E+08
2015	4.95E+07	1.97E+08	2.65E+08	1.30E+08	6.41E+08
Change ratio	5.54%	−6.64%	−8.24%	73.09%	3.14%

regions often need to consume more emergy. According to the results of emergy analysis, YRD 's emergy money ratio was 4.53E+12 sej/$ in 2009, which decreased to 3.92E+12 sej/$ in 2015. The emergy consumed per unit of GDP in 2015 decreased by 1.23E+12 sej compared with 2009, indicating that the social productivity of YRD is improving, and the local social economy has achieved greater development in 2015 than in 2009. The total emergy of YRD's ecosystem services in 2015 decreased by 10.89% compared with 2009, and the EMR decreased by 13.47%. Although the emergy value of the YRD's ecosystem services decreased in 2015, the rate of EMR decreased to a greater extent, which resulted in a higher total economic value of ecosystem services in 2015 than in 2009.

4.3. Analysis of economic value of YRD's ecosystem services

Based on the land use maps of YRD in 2009 and 2015, the corresponding economic values of different land use types were extracted (Table 8). From 2009 to 2015, the economic values of ecosystem services according to land use types in YRD decreased in the order grassland > farmland > bare land > water areas in descending order. The total value of grassland in 2009 was the highest at 2.43E+08$. Followed by farmland, with a total value of 1.95E+08$. The total value of bare land and water was 1.59E+08$ and 2.40E+07, respectively. In 2015, the economic value of grassland's ecosystem service was 2.55E+08$, with an increase of 4.94% compared with 2009. This was followed by farmland with a value of 1.87E+08$, representing a decrease of 4.10% compared with 2009. The total value of bare land and water was 1.72E+08$ and 2.84E+07$, respectively, which was 8.18% and 18.33% higher than in 2009, respectively. The total economic value of ecosystem services in YRD increased 3.05% from 2009 to 2015. The ecosystem service value per unit area in the study area was calculated by using the total economic value of ecosystem services divided by the total area of YRD. The results showed that the ecosystem service value per unit area was 7.33E+04 $/km^2 in 2009 and increased to 7.55E + 04 $/km^2 in 2015.

The land use classification data were used to calculate the unit area value of different types of land use and the annual average change from 2009 to 2015 (Table 9). The value of ecosystem service per unit area from 2009 to 2015 decreased in the order farmland > grassland > bare land > water areas. An upward trend was shown in all types of land use, among which the highest value was farmland. In 2009, the ecosystem service value of farmland was 1.23E+05 $/km^2, in 2015 it was 1.61E+05 $/km^2, with a growth rate of 30.92%; followed by grassland, the ecosystem service value per unit area in 2009 was 1.08E+05 $/km^2, in 2015 it was 1.32E+05 $/km^2, with an increase of 22.54%; the value of ecosystem services per unit area of bare land was 8.16E+04 $/km^2 in 2009 and 9.63E+04 $/km^2 in 2015, increased by 17.97%. In 2009, the ecosystem service value per unit area of water was 2.17E+04 $/km^2, which increased to 2.39E+04 $/km^2 in 2015, representing an increase rate of 10.37%.

Table 8
Analysis of economic value of ecosystem service according to land-use type.

	Grassland	Farmland	Built-up area	Water	Bare land	YRD
2009 ($)	2.43E+08	1.95E+08	–	2.40E+07	1.59E+08	6.22E+08
2015 ($)	2.55E+08	1.87E+08	–	2.84E+07	1.72E+08	6.41E+08
Change ratio (%)	4.94%	−4.10%	–	18.33%	8.18%	3.05%

5. Conclusion

Understanding the true value of ecosystem services can promote the maintenance and conservation of regional ecosystem service, provide scientific basis for formulating regional ecological civilization construction plans, sustainable development plans, and ecological compensation policies. This paper presents an integrated method that combined regional social economy and natural resources by emergy analysis to value regional ecosystem services. Emergy analysis was used to value the ecosystem services of YRD in 2009 and 2015. The results showed that the emergy of all types of ecosystem services and total emergy in YRD declined between the two years, indicating that YRD's ecosystem services were damaged. The emergy of all studied ecosystem services decreased, except the water conservation service, which increased considerably. However, this was mainly because the precipitation in 2015 was higher than that in 2009. Based on the emergy analysis for YRD, the EMR values were used to calculate the economic values of the studied ecosystem services and the total values. The results showed that the economic values of soil conservation and nutrient maintenance tended to decrease, while the economic values of carbon fixation, oxygen release, water conservation, and the total value showed an upward trend. Compared with 2009, the emergy of the YRD's ecosystem services as a whole declined in 2015. However, the economic valuation results showed that the economic values of YRD's ecosystem services in 2015 increased compared with 2009. This suggests that although the amount of YRD's ecosystem services was decreasing, the economic prices were rising, reflecting the increasing value of ecosystem services at the macroeconomic level. This result can also be explained by the theory of supply and demand in economics. When a certain resource or commodity becomes scarce, its market value should rise. In this study, we found even the quantity and emergy of ecosystem services were reduced, the economic value still raised due to the unit value of ecosystem services has increased.

We also visualized the quantity, emergy and economic value of YRD's ecosystem services, and displayed the spatial distribution of

Table 9
Analysis of economic value of ecosystem service per unit area.

	Grassland	Farmland	Built-up area	Water	Bare land	YRD
2009 ($/km^2)	1.08E+05	1.23E+05	–	2.17E+04	8.16E+04	7.33E+04
2015 ($/km^2)	1.32E+05	1.61E+05	–	2.39E+04	9.63E+04	7.55E+04
Change ratio (%)	22.54%	30.92%	–	10.37%	17.97%	3.00%

different types of ecosystem services intuitively through map layers. The quantity, emergy, and economic value of YRD's ecosystem services in any given area can be easily obtained from the layers. The comparison between different regions is also convenient. In the process of rapid urbanization, the visual analysis results of ecosystem services can provide useful information for decision makers in formulating regional development plans and ecological protection. Since the value of each type of ecosystem service in this study was measured on the basis of currency, the EMR was calculated based on the local total emergy and GDP. Thus, the calculation result is more reasonable for the local community. The results of this study can also provide scientific references in the process of exploration and formulation of ecological compensation policies. Decision makers can take corresponding measures based on the estimated economic value of ecosystem services and implement reasonable ecological compensation standards.

Acknowledgements

This work was supported by National Natural Science Foundation of China (No. 71403145, No. 71774032). Acknowledgement for the data support from "Soil Data Center, National Earth System Science Data Sharing Service Infrastructure, National Science & Technology Infrastructure of China (http://soil.geodata.cn)".

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