



# Land use change simulation and spatial analysis of ecosystem service value in Shijiazhuang under multi-scenarios

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## Abstract

Simulating changes in the value of ecosystem services caused by land use changes in large cities under multiple scenarios is of great significance for cities to formulate land use policies and improve ecosystem services. Take Shijiazhuang, which is in the process of rapid urbanization, as an example. Based on the remote sensing image data and statistical yearbook of 1988, 1998, 2008, and 2018 as the basic data to analyze and estimate the 30 years of land use and ecosystem service value changes in Shijiazhuang. According to this, the CA-Markov model was used to simulate the land use change in Shijiazhuang under three scenarios in 2030 and estimate the value of ecosystem services under each scenario, using grid tools to visually express the spatial distribution of ecosystem service values and the degree of agglomeration under three scenarios. The results indicate that the most obvious feature of land use change in Shijiazhuang from 1988 to 2018 was that the farmland area decreased year by year, the built-up expanded rapidly, the farmland area decreased by 86,874.75 hm<sup>2</sup> in 30 years, and the built-up increased by 154,711.90 hm<sup>2</sup>. In 1988, 1998, 2008, and 2018, the ecosystem service value of Shijiazhuang was 32.578 billion yuan, 32.799 billion yuan, 29.944 billion yuan, and 31.251 billion yuan respectively. In 2030, under three scenarios of natural development, farmland protection, and ecological protection, the value of ecosystem services is 331.111 billion yuan, 33.670 billion yuan, and 33.891 billion yuan in order. The hot spots are mainly concentrated in the northwest and southwest of Shijiazhuang, and cold spots are concentrated in the eastern cities, counties, and districts. Based on changes in land use brought about by urban expansion, simulating the value of ecosystem services under multiple scenarios in the future, providing scientific guidance for building urban ecological networks, and realizing sustainable urban ecological development.

**Keywords** Change of land use · Ecosystem service value · CA-Markov · Hot spot analysis

## Introduction

Ecosystem service (ES) refers to life support products and services directly or indirectly obtained through the structure, processes, and functions of the ecosystem (Xie et al. 2015; Huang et al. 2017; He et al. 2021). The study found that more than

60% of ecosystem services worldwide have experienced significant degradation (Fu and Zhang 2014; Himes et al. 2018). Land use change (LUC) affects the formation, supply, and distribution of ecosystem services by changing the structure, function, and spatial pattern of ecosystems (He et al. 2018; Jiang et al. 2020; Woldeyohannes et al. 2020). The rapid expansion of urban space has led to a sharp decline in urban agricultural land and ecological land, significantly changing the structure of regional land use, resulting in the weakening and degradation of ecosystem services, which has seriously threatened social equity and restricted the sustainable development of cities (Masek et al. 2000). At present, China is undergoing another rapid urbanization process. The expansion of urban built-up encroaching on the land space of farmland and forest will lead to the increasingly prominent contradictions between regional urban development, agricultural land protection, and ecological conservation (Egoh et al. 2007; Liu et al. 2015; Zhao et al. 2021). With the rapid expansion of the city

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and changes in land use, LUC has caused huge changes in the internal structure, process, and function of the ecosystem (Wu and Li 2019; Liu and Kuang 2019; Daily 2000), ecosystem services values (ESV) in terms of regulation, supply, and culture (Hang et al. 2015; Lautenbach et al. 2011). More and more researchers, managers, and the general public around the world have realized the importance of ecosystem services to urban development and have incorporated them into decision-making management. Exploring the impact of land use changes on ecosystem services in the process of urbanization has become the focus of global human and social well-being research, and is also an effective tool to support sustainable urban development decision-making. It is of great significance for optimizing the spatial pattern of the country and ensuring the ecological security of the country.

At present, domestic and foreign scholars have conducted a lot of researches on the impact of LUC on ESV. Costanza et al. (1997) and some other experts formulated the global ESV equivalent factor table in 1997, which became an important basis for ecosystem service value assessment. Domestic scholar Xie et al. (2008) and some other experts developed the Equivalent Scale of Ecological Service Value per Unit Area of Chinese Terrestrial Ecosystem based on the study of Costanza, which is widely used by domestic scholars. As the research progresses, evaluation of the value of ESs by domestic and foreign scholars (Jiang et al. 2018), trade-offs and collaboration (Shui et al. 2019; Vallet et al. 2018), spatial flow (Mario et al. 2018), and optimization decision (Song 2018) had been explored. Among them, the impact of urban expansion on ESV has become one of the research hot spots (Niemelä et al. 2010). From the perspective of research scale, scholars have mainly studied lakes (Karki et al. 2018; Yang et al. 2020a; Yang et al. 2019; Yang et al. 2018), watersheds (Kertész et al. 2019), cities (Xu et al. 2020; Gómez-Baggethun and Barton 2013; Kremer et al. 2016), greenland (Yang et al. 2017; Yang et al. 2020a), and wetlands (Wondie 2018) as research areas, and conducted studies on the impact of LUC on ESV. In terms of research content, it mainly focuses on the theoretical basis of ecosystem services (Costanza et al. 2014; Millennium Ecosystem Assessment. 2005), driving forces (Yang et al. 2020b; Zhang et al. 2018; Huang et al. 2019), spatiotemporal changes (Estoque and Murayama 2015), and influencing factors (Yang et al. 2015; Hao et al. 2017; Li et al. 2019a, b), etc. The research methods are mainly statistical analysis (Eigenbrod et al. 2011) and spatial analysis (Castro et al. 2015; Bagstad et al. 2013; Li et al. 2019a, b), and more and more attention is paid to the role research and practice in land use planning (Wang et al. 2020; Liu et al. 2019). The above studies mainly measure LUC and ESV in the current or past period, and there are few studies on the assessment of ecosystem services in the future period. Some domestic and foreign scholars have tried to simulate the value of ecosystem services under multiple scenarios. For example, Egoh et al. (2011) and some other experts used Marxan model

to simulate the service status of grassland ecosystem in South Africa under different scenarios; Estoque and Murayama (2012) studied the impacts of land use change on ecosystem service value under future forest protection scenarios and natural development scenarios in Baguio City; Kubiszewski et al. (2017) estimated the value of ecosystem services in four scenarios, namely, the market-oriented scenario and the policy improvement scenario on a global scale, and found that the value of ecosystem services in the four scenarios could differ by \$81 trillion per year by 2050; Du et al. (2019) and some other experts used the Logistic-CA-Markov model to simulate the quantitatively evaluated water conservation services, carbon sequestration services, soil conservation services, and food supply services in Quanzhou, Fujian Province, in 2030, under the natural scenarios, planning scenarios, and protection scenarios; Ouyang et al. (2020) and some other experts used the urban agglomeration under rapid urbanization as an example to simulate the impact of LUC on ESV under three scenarios. These studies provide practical reference value for the government to formulate land use plans. However, most of the research is based on the macro scale, and it cannot accurately express the spatial difference of ecosystem service value in the study area.

This article takes Shijiazhuang as the research object and analyzes the changes in land use and ecosystem service value of Shijiazhuang from 1988 to 2018. This article sets up natural development scenario, farmland protection scenario, and ecological protection scenario. CA-Markov model is adopted to simulate the land use situation of Shijiazhuang City in 2030 under three scenarios. On this basis, grid tools are used to visually express the spatial distribution of ecosystem service values under different preferences and the degree of agglomeration. It is expected to provide a theoretical basis and decision-making reference for the future ecological environment quality improvement of large cities and the formulation of sustainable urban ecological development policies.

## Study area and data sources

### Study area

Shijiazhuang (37° 27'–38° 47' N, 113° 30'–115° 20' E) is located in the central and southern parts of Hebei Province, and is an important central city and food production base in northern China. It covers an area of about 14,066.73 km<sup>2</sup> and has more than 19 districts and counties and 3 county-level cities. With the Taihang Mountains in the west and the North China Plain in the east, Shijiazhuang has various land types. The terrain is high in the west and low in the east, with a relative height of 2244 m (Fig. 1). Winter is cold and dry while summer is hot and rainy in this city, the annual precipitation is 400–750 mm, and the average annual temperature is between 10 and 20 °C,

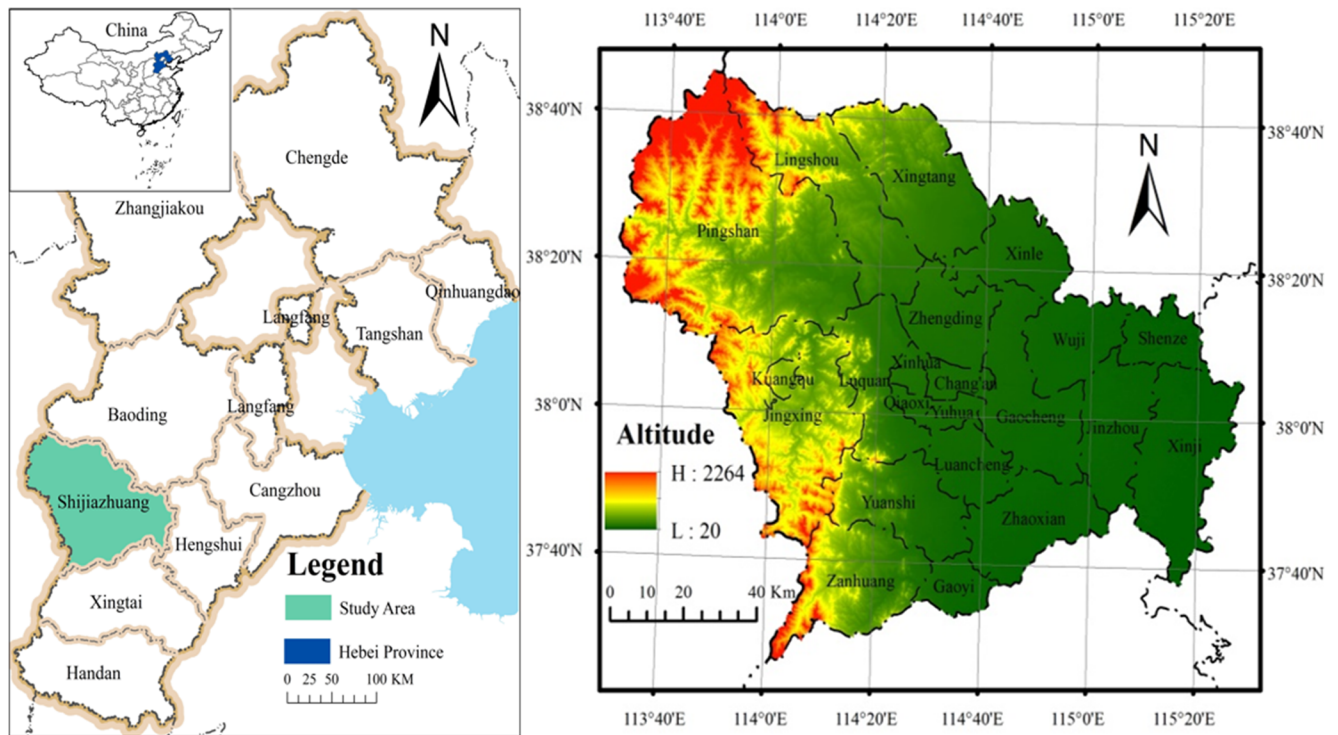


Fig. 1 Location of Shijiazhuang

which is a typical temperate monsoon climate. The economic development of Shijiazhuang is rapid, and the regional GDP in 2018 reached 594.223 billion yuan. The permanent population is 10.8799 million, the urban permanent population is 69.167 million, and the urbanization rate is 63.57%. From 1988 to 2018, built-up area in Shijiazhuang increased by 122%. Shijiazhuang is a rapidly expanding city in the past few decades, and its land use structure has changed dramatically, which is very representative. At the same time, the same thing happened in many cities in China. Shijiazhuang is a city with a population of more than 10 million, so the study of Shijiazhuang is more able to find the law. In the context of rapid urbanization and industrialization, a series of problems such as the demand for built-up, food security, and water shortages in Shijiazhuang pose serious challenges to ecosystem services, ecological civilization, and ecological security. Shijiazhuang is an ideal research area for studying land use change and ecosystem service value evolution.

**Data sources**

The data used in this research includes remote sensing image data, land use data, food data, DEM elevation data, slope data, socio-economic data and population data, road data, and county point coordinate data. Among them: (1) Remote sensing images are downloaded from the geospatial data cloud platform Landsat4-5/TM and Landsat-8/OLI satellites, from the data center of resources and environment science, Chinese Academy of Sciences (<http://www.resdc.cn>), the spatial

resolution is 30 m; (2) Remote sensing images of Shijiazhuang in 1988, 1998, 2008, and 2018 are used as the data source. Combined with the land use characteristics of Shijiazhuang and the classification system of the Chinese Academy of Sciences resource and environmental data cloud platform, land use is divided into six categories: farmland, forest, grassland, built-up, water area, and unused land. ENVI5.3.1 software was used to supervise the classification and manual visual interpretation of remote sensing images. After inspection, the accuracy of the fourth phase images reached more than 85%, which can be used for research (see Fig. 2); (3) Grain data such as yield, unit price, and sown area of wheat, corn, and millet are derived from National Compendium of Agricultural Product Cost and Benefit Information 2018; (4) DEM elevation data comes from a geospatial data cloud platform, and slope data is extracted from DEM elevation data; (5) GDP and POP data come from the 1 km×1 km interpolation data of the resource and environment data cloud platform; (6) Highway, railway line data and county point data all come from the resource and environment data cloud platform.

**Research method**

**Ecosystem service value assessment**

American scholar Costanza and others have developed a global ESV equivalent factor table, which has laid a foundation for

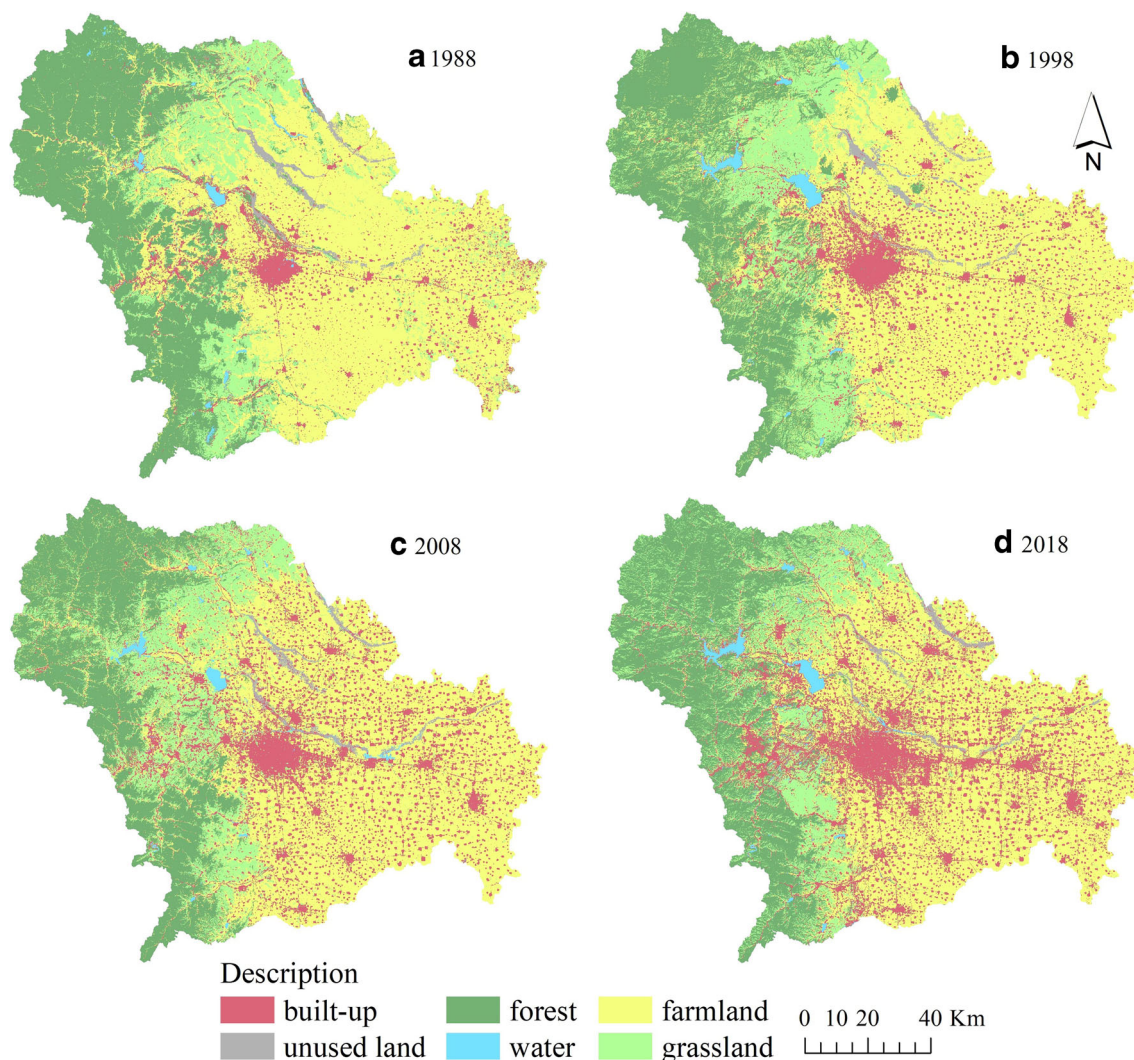


Fig. 2 Land use data of Shijiazhuang City in the four phases of 1988, 1998, 2008, and 2018

the study of ESV evaluation (Costanza et al. 1997). This article uses the method of value evaluation based on the amount of money and the research results of scholars such as Xie Gaodi and others (Xie et al. 2015; Xie et al. 2003; Xie et al. 2001), Equivalent Value Table of Ecological Services per Unit Area of China’s Terrestrial Ecosystem. This study assigns values to ecosystem services of various land use types in Shijiazhuang (Table 1).

The ESV of Shijiazhuang is calculated by formula (1) and formula (2).

$$ESV = \sum_{i=1}^n A_i \times VC_i \tag{1}$$

$$VC_i = \sum_{j=1}^k EC_j \times E_a \tag{2}$$

where  $ESV$  is the ecosystem service value, the unit is yuan/year;  $i$  is the type of land use;  $j$  is the type of ecosystem service;  $A_i$  is the area of land use type  $i$ , the unit is  $hm^2$ ;  $VC_i$

is the ecosystem service value per unit area of land use type  $i$ , the unit is  $yuan\ hm^{-2}\ a^{-1}$ ;  $EC_j$  is the value equivalent of ecosystem service value of item  $j$  of a certain type of land use; and  $E_a$  is the economic value of 1 unit of ecosystem services, the unit is  $yuan\ hm^{-2}\ a^{-1}$ .

In order to more accurately determine the economic value of 1 unit of ecosystem services in the study area, combined with the field situation in Shijiazhuang, formula (3) is used to modify this value. The economic value of wheat, corn, and millet in 2017 was selected for correction, and the results showed that the economic value of 1 unit of ecosystem service in Shijiazhuang was  $1933.31\ yuan\ hm^{-2}\ a^{-1}$ .

$$E_a = 1/7 \sum_{i=1}^n \frac{m_i p_i q_i}{M} \tag{3}$$

where “ $E_a$ ” is the economic value of 1 unit of ecosystem service and the unit is  $yuan\ hm^{-2}\ a^{-1}$ ; “ $p$ ” is the type of food crop; “ $m_i$ ” is the average price of the  $i$ th grain crop in Shijiazhuang and the unit is yuan/kg; “ $p_i$ ” is the yield of the

**Table 1** Ecosystem service equivalent value per unit area

| First category        | Second category           | Farmland | Forestland | Grassland | Built-up | Water  | Unused land |
|-----------------------|---------------------------|----------|------------|-----------|----------|--------|-------------|
| Provisioning services | Food production           | 0.85     | 0.29       | 0.38      | 0        | 0.8    | 0           |
|                       | Raw material production   | 0.4      | 0.66       | 0.56      | 0        | 0.23   | 0           |
|                       | Water Resource Supply     | 0.02     | 0.34       | 0.31      | 0        | 8.29   | 0           |
| Regulating services   | Gas regulation            | 0.67     | 2.17       | 1.97      | 0        | 0.77   | 0.02        |
|                       | Climate regulation        | 0.36     | 6.5        | 5.21      | 0        | 2.29   | 0           |
|                       | Purify the environment    | 0.1      | 1.93       | 1.72      | 0        | 5.55   | 0.01        |
|                       | Hydrological regulation   | 0.27     | 4.74       | 3.82      | 0        | 102.24 | 0.03        |
| Supporting services   | Soil conservation         | 1.03     | 2.65       | 2.4       | 0        | 0.93   | 0.02        |
|                       | Maintain nutrient cycling | 0.12     | 0.2        | 0.18      | 0        | 0.07   | 0           |
|                       | Biodiversity              | 0.13     | 2.41       | 2.18      | 0        | 2.55   | 0.02        |
| Cultural services     | Aesthetic landscape       | 0.06     | 1.06       | 0.96      | 0        | 1.89   | 0.01        |

$i$ th food crop and the unit is  $\text{kg}/\text{hm}^2$ ; “ $q_i$ ” is the planting area of the  $i$ th food crop and the unit is  $\text{hm}^2$ ; and “ $M$ ” is the total planted area of food crops and the unit is  $\text{hm}^2$ .

### Scenario simulation and settings

#### CA-Markov

The Markov model (Jiang et al. 2006; Wang et al. 2011) uses the relevant knowledge of probability theory to study the probability of something changing from one state to another state and predicts the state of future things according to the rules obtained from the research. It is a prediction of the future quantity. Its formula is:

$$S_{(t+1)} = S_t \times P_{ij} \tag{4}$$

where “ $S_t$ ” is the state of the land use system at time  $t$ ; “ $S_{(t+1)}$ ” is the state of the land use system at time  $t + 1$ ; and “ $P_{ij}$ ” is the land use transfer matrix.

The Cellular Automata (CA) model is a discrete model of time, space, and state. Through the interaction of cells with different spatiotemporal characteristics, the dynamic model of the spatiotemporal evolution of complex systems is simulated (Yue et al. 2019; Wang et al. 2015).

$$S_{t+1} = f(S_t, N) \tag{5}$$

where “ $S$ ” is the finite and discrete set of states of the cell; “ $N$ ” is the neighborhood of the cell; “ $t$ ” and “ $t + 1$ ” stand for different times; and “ $f$ ” is the local space cell conversion rule.

The CA-Markov model combines the Markov model and the CA model to make up for the deficiencies of the respective

models, and to achieve double prediction of the number and spatial location of land use types (Han et al. 2009; Srikanta et al. 2020).

#### Scene setting

In order to better promote the coordinated development of urbanization process, farmland protection, and ecological protection in Shijiazhuang, this study set up three kinds of land use change simulation scenarios:

1. Natural development scenario. The natural development scenario is a scenario of spontaneous evolution based on the land use change law from 2008 to 2018, which simulates the land use structure in 2030 without any constraints on the Markov transfer matrix.
2. Farmland protection scenario. Based on the future population growth forecast and food security requirements of Shijiazhuang City, strictly observe the red line of farmland, and the amount of farmland in 2030 will not be less than 95% of the total amount of farmland, in 2018. Based on the concept of farmland, protection, this paper simulates the future situation of land use in Shijiazhuang City under the constraints of farmland, protection. In the setting of land use transfer rules, it restricts the transformation of farmland, to other land types to meet the future food supply.
3. Ecological protection scenario. In order to prevent the rapid and disorderly expansion of the city from causing damage to the ecological environment and coordinate the relationship between urban development and ecological protection, ecological protection scenarios are set up.

Based on the concept of ecological protection, this paper simulates the future land use scenarios of Shijiazhuang City under the constraints of woodland and grassland protection, and strictly restricts the conversion of woodland, grassland and water area to built-up land in the setting of land use transfer rules.

### ESV hot spot analysis

Hot spot analysis (Getis-Ord  $G_i^*$ ) (Lei et al. 2020) is a common tool used to identify the spatial distribution of cold spots and hot spots. In this paper, hot spot analysis can be used to reflect whether the ESV in Shijiazhuang has high-value agglomeration (hot spots) and low-value agglomeration (cold spots), and to determine the spatial clustering locations of high-value and low-value areas. Its formula is:

$$G_i^* = \frac{\sum_{j=1}^n w_{i,j} x_j - X \sum_{j=1}^n w_{i,j}}{\sqrt{\frac{n \sum_{j=1}^n w_{i,j}^2 - \left(\sum_{j=1}^n w_{i,j}\right)^2}{(n-1)}}} \quad (6)$$

$$X = \frac{1}{n} \sum_{j=1}^n x_j \quad (7)$$

$$S = \sqrt{\frac{1}{n} \sum_{j=1}^n x_j^2 - (X)^2} \quad (8)$$

where “ $n$ ” is the number of spatial grid units; “ $x_i$ ” and “ $x_j$ ” are observed values of unit “ $i$ ” and unit “ $j$ ”; “ $w_{ij}$ ” is a spatial weight matrix based on the spatial “ $k$ ” adjacency relationship. If the *ESV* is high within a certain range, it becomes a hot spot with significant statistical significance. It is called an *ESV* hot spot area, indicating that the ecosystem service value is greater in this area; if the *ESV* is low within a certain range, it will become a cold spot with significant statistical significance. It is called the *ESV* cold spot zone, indicating that the ecosystem service value is small in this zone.

## Result analysis

### Changes of LUC and *ESV* in Shijiazhuang from 1988 to 2018

#### Overall characteristics of land use change in Shijiazhuang City from 1988 to 2018

It can be seen from Table 2 that the overall characteristics of LUC in Shijiazhuang from 1988 to 2018 are as follows: The area of arable land is constantly decreasing, and the area of built-up is increasing. From 1988 to 2018, farmland accounted

for the largest proportion of the land use structure in Shijiazhuang, at 45.52%, 46.21%, 44.34%, and 39.35%, respectively. Farmland area showed a downward trend, from 640,356.03  $\text{hm}^2$  in 1988 to 553,481.28  $\text{hm}^2$  in 2018, a decrease of 86,874.75  $\text{hm}^2$ ; the reduction rate was 13.57%; and the rate of arable land reduction was faster. Since the Reform and Opening, Shijiazhuang has developed rapidly, and the expansion of built-up has been accelerating. From 1988 to 2018, the built-up in Shijiazhuang increased from 125,924.94  $\text{hm}^2$  to 280,636.83  $\text{hm}^2$ , built-up area increased by 154,711.90  $\text{hm}^2$ , the growth rate was 122.86%, and the proportion of built-up area was 8.95%, 10.24%, 15.52%, and 19.95%; the area of woodland and grassland has been relatively stable for 30 years while water area has become less. The rate of reduction of unused land in Shijiazhuang is also very obvious. From 1988 to 2018, the area of unused land decreased from 53,248.85 to 10,979.37  $\text{hm}^2$ , with a reduction rate of 79.03%.

It can be seen from Fig. 2 that the overall spatial utilization characteristics of Shijiazhuang are as follows: forest and grassland in the west, farmland and built-up in the east are widely distributed. The main reason is that the terrain of Shijiazhuang is high in the west and low in the east, the Taihang Mountains are in the west, and the North China Plain is in the east. From the Map of Shijiazhuang Land Use Type (1988–2018), we can see that urban expansion is the key factor that causes changes in land use types. In the process of rapid urbanization, farmland has been invaded and converted into built-up. The expansion of built-up in the east is larger and the expansion speed is faster; the expansion of built-up in the west mainly occurs in the Jingxing kuangqu.

#### Changes of *ESV* in Shijiazhuang from 1988 to 2018

LUC caused the change of *ESV* in Shijiazhuang. As can be seen from Table 3, the value of ecosystem services in Shijiazhuang was 32.578 billion yuan, 32.799 billion yuan, 29.944 billion yuan, and 31.251 billion yuan from 1988 to 2018, showing a trend of decreasing first and then increasing. Among them, the ecosystem service value of farmland decreased from 4.97 billion yuan in 1988 to 4.295 billion yuan in 2018, mainly due to the continuous decrease of farmland area in Shijiazhuang from 1988 to 2018. The forest contributed the most to the *ESV* in Shijiazhuang, which was 15.139 billion yuan, 15.639 billion yuan, 14.350 billion yuan, and 14.791 billion yuan in four time periods, accounting for 46.47%, 47.68%, 47.92%, and 44.14%, showing a weak downward trend. From 1988 to 2018, the *ESV* of grassland was as follows: 8.855 billion yuan, 8.836 billion yuan, 8.269 billion yuan, and 7.901 billion yuan. The *ESV* of the grassland did not change significantly and began to decrease rapidly after 1998. Since 1998, the economy of Shijiazhuang City has entered a period of steady growth of medium and high

**Table 2** Changes of different land use types in Shijiazhuang City from 1988 to 2018 (hm<sup>2</sup>)

| Land use type |                         | Farmland   | Forestland | Grassland  | Built-up   | Water     | Unused land |
|---------------|-------------------------|------------|------------|------------|------------|-----------|-------------|
| 1988a         | Area (hm <sup>2</sup> ) | 640,356.03 | 340,848.98 | 232,370.82 | 125,924.94 | 14,823.65 | 53,248.85   |
|               | Proportion (%)          | 45.52      | 24.23      | 16.52      | 8.95       | 1.05      | 3.72        |
| 1998a         | Area (hm <sup>2</sup> ) | 649,986.30 | 352,103.31 | 231,866.55 | 144,094.50 | 13,481.01 | 15,141.60   |
|               | Proportion (%)          | 46.21      | 25.03      | 16.48      | 10.24      | 1.00      | 1.08        |
| 2008a         | Area (hm <sup>2</sup> ) | 623,771.37 | 323,091.72 | 217,006.02 | 218,334.42 | 10,206.54 | 14,263.20   |
|               | Proportion (%)          | 44.34      | 22.97      | 15.43      | 15.52      | 0.73      | 1.01        |
| 2018a         | Area (hm <sup>2</sup> ) | 553,481.28 | 337,516.02 | 207,353.70 | 280,636.83 | 16,706.07 | 10,979.37   |
|               | Proportion (%)          | 39.35      | 23.99      | 14.74      | 19.95      | 1.19      | 0.78        |
| 1988–2018a    | Rate of area change (%) | −86,874.75 | −3332.96   | −25,017.10 | 154,711.90 | 1882.42   | −41,369.50  |
| 1988–2018a    | Rate of area change (%) | −13.57     | −0.98      | −10.77     | 122.86     | 12.70     | −79.03      |

speeds. The demand for urban built-up is increasing, and grassland is occupied by built-up, resulting in a decrease ESV in grassland. ESV in waters and unused land show two opposite development trends. The 30-year growth rate of ESV in waters has reached 79.86% and the decrease rate of ESV in unused land is 99.46%. Due to the small base area of these two types of land, it has little impact on the overall ESV of Shijiazhuang. In general, forest and grassland are the main sources of ESV in Shijiazhuang. Strict protection of forest and grassland and maintenance of ecosystem function are important directions of ecological protection in Shijiazhuang.

The individual ESV changes are shown in Table 4. According to the result of ESV, they are hydrological regulation, climate regulation, soil conservation, gas regulation, biodiversity, clean environment, food production, aesthetic landscape, raw material production, water supply, and maintenance of nutrient cycle. Among them, hydrological adjustment and climate adjustment ESV account for a large proportion, both of which account for more than 50% of the total value. The hydrologically adjusted ESVs from 1988 to 2018 were 8.415 billion yuan, 7.952 billion yuan, 6.914 billion

yuan, and 8.225 billion yuan respectively. The ESV for climate regulation was 7.143 billion yuan, 7.28 billion yuan, 6.732 billion yuan, and 6.796 billion yuan respectively. The ESV of grain production and raw material production continued to decrease, and during the study period, they decreased by 161 million yuan and 98 million yuan. Aesthetic landscape, biodiversity, maintenance of nutrient circulation, soil exploration, purification of the environment, and gas regulation all belong to the trend of increasing first and then decreasing, but the degrees of increase and decrease are relatively small. Increased water area increases the value of water supply.

**CA-MARKOV simulation verification**

In this study, Markov and CA-Markov modules in IDRISI software were used. The land use data (1988, 1998, 2008, and 2018) were obtained by manual visual interpretation of ENVI5.3.1. First, using 2008 as the base year, the land use types of Shijiazhuang in 2018 are predicted and compared with the actual land use types of Shijiazhuang in 2018 to

**Table 3** Ecosystem service value changes of each land use type of Shijiazhuang City from 1988 to 2018 (units: 10<sup>8</sup> yuan)

| Land use type |                        | Farmland | Forestland | Grassland | Built-up | Water | Unused land | Total  |
|---------------|------------------------|----------|------------|-----------|----------|-------|-------------|--------|
| 1988a         | ESV                    | 49.70    | 151.39     | 88.55     | 0.00     | 36.35 | 0.11        | 325.78 |
|               | Proportion (%)         | 15.26    | 46.47      | 27.18     | 0.00     | 11.16 | 0.03        | 100    |
| 1998a         | ESV                    | 50.44    | 156.39     | 88.36     | 0.00     | 32.77 | 0.03        | 327.99 |
|               | Proportion (%)         | 15.38    | 47.68      | 26.94     | 0.00     | 10.00 | 0.00        | 100    |
| 2008a         | ESV                    | 48.41    | 143.50     | 82.69     | 0.00     | 24.81 | 0.03        | 299.44 |
|               | Proportion (%)         | 16.17    | 47.92      | 27.61     | 0.00     | 0.08  | 0.00        | 100    |
| 2018a         | ESV                    | 42.95    | 149.91     | 79.01     | 0.00     | 40.61 | 0.02        | 312.51 |
|               | Proportion (%)         | 13.74    | 47.97      | 25.28     | 0.00     | 12.99 | 0.00        | 100    |
| 1988–2018a    | Rate of EVS change (%) | −6.75    | −1.48      | −9.54     | 0.00     | 29.03 | −0.1094     | 13.83  |
| 1988–2018a    | Rate of EVS change (%) | −13.58   | −0.98      | −10.77    | 0.00     | 79.86 | −99.46      | 4.11   |

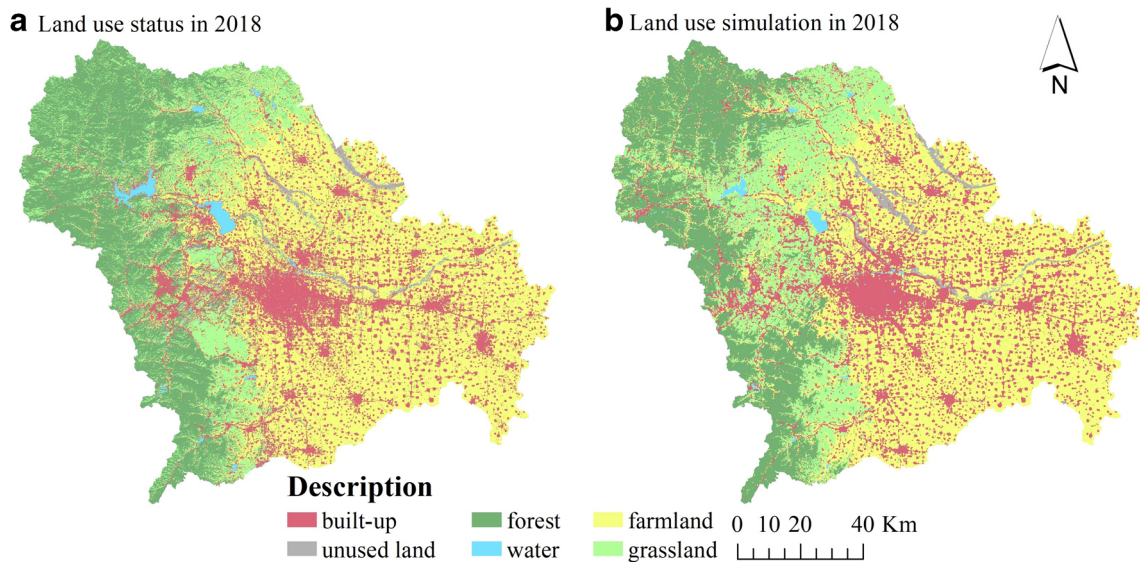
**Table 4** Ecosystem service value changes of each ecosystem service type of Shijiazhuang City from 1988 to 2018 (units:  $10^8$  yuan)

| Ecosystem services    |                           | ESV    |        |        |        |
|-----------------------|---------------------------|--------|--------|--------|--------|
|                       |                           | 1988   | 1998   | 2008   | 2018   |
| Provisioning services | Food production           | 14.39  | 14.58  | 13.83  | 12.78  |
|                       | Raw material production   | 11.90  | 12.10  | 11.35  | 10.92  |
|                       | Water resource supply     | 6.26   | 6.12   | 5.31   | 6.36   |
| Regulating services   | Gas regulation            | 31.72  | 32.26  | 30.09  | 29.51  |
|                       | Climate regulation        | 71.43  | 72.80  | 67.32  | 67.96  |
|                       | Purify the environment    | 23.31  | 23.58  | 21.60  | 22.38  |
|                       | Hydrological regulation   | 81.15  | 79.52  | 69.14  | 82.25  |
| Supporting services   | Soil conservation         | 41.33  | 42.03  | 39.27  | 38.28  |
|                       | Maintain nutrient cycling | 3.64   | 3.70   | 3.47   | 3.34   |
|                       | Biodiversity              | 28.06  | 28.51  | 26.30  | 26.71  |
| Cultural services     | Aesthetic landscape       | 12.61  | 12.78  | 11.76  | 12.03  |
|                       | Total                     | 325.78 | 327.99 | 299.44 | 312.51 |

verify the accuracy of the CA-Markov model simulation. Specific steps are as follows:

1. Conversion rules. Using the Markov model, the time period is set to 10a and the proportional error is set to 0.15, and the annual land use transfer area matrix and transfer probability matrix of Shijiazhuang City from 1998 to 2008 and 2008 to 2018 are obtained respectively.
2. Accuracy verification. Before using the CA-Markov model to predict land use types in Shijiazhuang in 2030, the prediction accuracy of the CA-Markov model should be tested. The verification process is as follow: First, use 2008 as the starting year to predict the land use type of Shijiazhuang in 2018, use the cross tab module in IDRISI software, compare the 2018 forecast map with the actual land use type in 2018, and calculate the kappa value (generally, when  $\text{kappa} > 0.75$ , the consistency of the predicted simulation is high; when  $0.4 \leq \text{kappa} \leq 0.75$ , the consistency is general; when  $\text{kappa} < 0.4$ , the consistency is poor.). After passing the accuracy test, the land use type of Shijiazhuang in 2030 can be predicted. Kappa statistics is a more commonly used accuracy test model.
3. Make a proper atlas. Make a proper atlas. Suitability atlas refers to the probability map that a certain land use type is converted to other land use types. Suitability atlas is an important part of setting conversion rules. According to the research results of previous scholars and the specific situation of Shijiazhuang City, this study uses the 'Decision Wizard' module of IDRISI software to make the suitability atlas. Seven factors including DEM elevation, slope, GDP, pop, distance from county, distance from highway and distance from railway were selected to make suitability atlas. The specific settings are as follows:
  - (a) Natural development scenarios. In the conversion rules, there is no restriction on any land class conversion. Under this scenario, the change rate of each land use type is consistent with that of 2008–2018.
  - (b) Farmland protection scenarios. The main goal of this scenario is to give priority to the protection of farmland, resources. In the process of model implementation, the specific performance is as follows: firstly, the current situation of farmland, resources in 2018 is taken as a restrictive factor to strictly restrict the transformation of farmland, resources to other land use types. Secondly, adjust the parameters of suitability factors of farmland, protection scenarios in 2030. The results show that the optimum altitude is below 300m and 300–900m, and the suitability decreases when the altitude is above 900m; the optimum slope is  $0-3^\circ$  and the suitability degree gradually decreases when the altitude is above  $3^\circ$  and the suitability decreases when the altitude is less than 3km; the suitability decreases when the altitude is more than 3km; other parameters remain unchanged.
  - (c) Ecological protection scenario. In this situation, the most important goal is to ensure that forest land, grassland and water area related to ecological environment are not occupied by built-up land. In the process of model implementation, the specific performance is as follows: firstly, the forest land, grassland and water area in 2018 are taken as restrictive factors to strictly restrict their transformation to built-up and farmland. Secondly, adjust the parameters of ecological protection scenario suitability factor in 2030. The results show that the altitude below 600m is the most suitable, 600–1200m is the most suitable, and more than 1200m is the least suitable;





**Fig. 3** Land use status map (a) and simulation map (b) of Shijiazhuang in 2018

the slope at 0–5° is the most suitable, 5–15° is the most suitable, and 15° is the least suitable; the distance within 3km from town is the most suitable, and more than 3km is the least suitable; other parameters remain unchanged.

4. Construct a CA filter. A standard 5×5 filter is used.
5. Determine the number of CA cycles. Using 2008 as the base period, the cycle number is set to 10a and the land use change in 2018 is simulated. The comparison between the land use status in 2018 and the simulation results in Fig. 3b is shown in Fig. 3b. The kappa coefficient is 0.82, which meets the research needs.

### Analysis of LUC and ESV in Shijiazhuang City under various scenarios

#### LUC simulation of Shijiazhuang in multiple scenarios

According to the two phases of LUC in Shijiazhuang in 2008 and 2018, the conditions of farmland protection and

ecological protection were added to the LUC simulation in Shijiazhuang, and three kinds of LUC simulation scenarios in Shijiazhuang were established (Table 5). Under the natural development scenario, the built-up area of Shijiazhuang was 340,615.53 hm<sup>2</sup> in 2030, an increase of 59,978.70 hm<sup>2</sup> compared with 2018; the farmland area decreased by 15.79% compared with 2018. Grassland and water area increased slightly. Under the protection of farmland, the area of farmland in Shijiazhuang in 2030 is 528,775.83 hm<sup>2</sup>; the area of built-up is 277,615.89 hm<sup>2</sup>. In this scenario, although arable land is still decreasing, the rate of decline is relatively slow. Under the ecological protection scenario, the area of farmland in Shijiazhuang in 2030 was 501,911.73 hm<sup>2</sup>; the grassland area increased significantly from 2018 to 254,111.58 hm<sup>2</sup>, an increase of 22.55%. The built-up area is 292,916.28 hm<sup>2</sup> (Fig. 4).

From a horizontal perspective, the expansion of built-up under the natural development scenario is larger than that of the other two scenarios. Among them, the expansion rate of Shijiazhuang urban area in the east and the Kuangqu in the west is particularly obvious. Under the arable land protection scenario and the ecological protection scenario, the expansion

**Table 5** The area of each land use type under three development scenarios is simulated (hm<sup>2</sup>)

| Land use type                  | Farmland   | Forestland | Grassland  | Built-up   | Water     | Unused land |
|--------------------------------|------------|------------|------------|------------|-----------|-------------|
| 2018a                          | 553,481.28 | 337,516.02 | 207,353.70 | 280,636.83 | 16,706.07 | 10,979.37   |
| Natural development scenario   | 466,071.39 | 328,918.41 | 245,107.98 | 340,615.53 | 22,807.98 | 3151.98     |
| Farmland protection scenario   | 528,775.83 | 328,918.41 | 245,108.88 | 277,615.89 | 23,103.18 | 3151.08     |
| Ecological protection scenario | 501,911.73 | 331,618.41 | 254,111.58 | 292,916.25 | 22,967.28 | 3148.02     |

scope of built-up in Shijiazhuang is smaller than that in the natural development scenario, and the land occupation area of farmland, grassland, and forest is smaller than that in the natural development scenario. The city’s development speed is more in line with the actual law.

The natural development scenario of Shijiazhuang in 2030 is based on the land use changes in 2008 and 2018, and is simulated without external intervention. Under the influence of this law, Shijiazhuang will be in line with the rapid urbanization trend in 2030. However, the unhealthy and rapid development of cities in the past has had a serious negative impact on the land use pattern, which is not conducive to the sustainable development of Shijiazhuang. Under the protection of farmland scenario, the concept of protecting farmland is strictly observed. The area of farmland has increased significantly compared with the natural development scenario. The expansion of built-up has slowed down, which has made important contributions to ensuring food security. Strengthen ecological environment protection under the ecological protection scenario, strictly restrict the conversion of forest and grassland to other types of land use and protect the urban ecological environment.

### Variation characteristics of ESV in Shijiazhuang under various scenarios

Land ESV is mainly related to land use type area. Compared with the ESV of various lands in 2018, under the natural development scenario of Shijiazhuang in 2030, the ESV of farmland and forest has decreased and the ESV of farmland has decreased significantly. The ESV of grasslands and waters increased. Compared with natural development scenarios, the ESV changes in the other two scenarios are different. It can be seen from Table 6 that under the protection of farmland, the ESV of farmland is 487 million yuan higher than the natural development scenario, which is mainly related to the restrictive conditions that strictly restrict the transfer of farmland. Under the ecological protection scenario, the ESV of farmland, forest, grassland and water are higher than that of natural development scenario. In this scenario, forest, grassland, water, and other ecological land are strictly protected, so that ESV has increased.

To further analyze the ESV and its spatial changes in Shijiazhuang under multiple scenarios, we use the fishing net tool in the ArcGIS software to create a 2 km × 2 km square

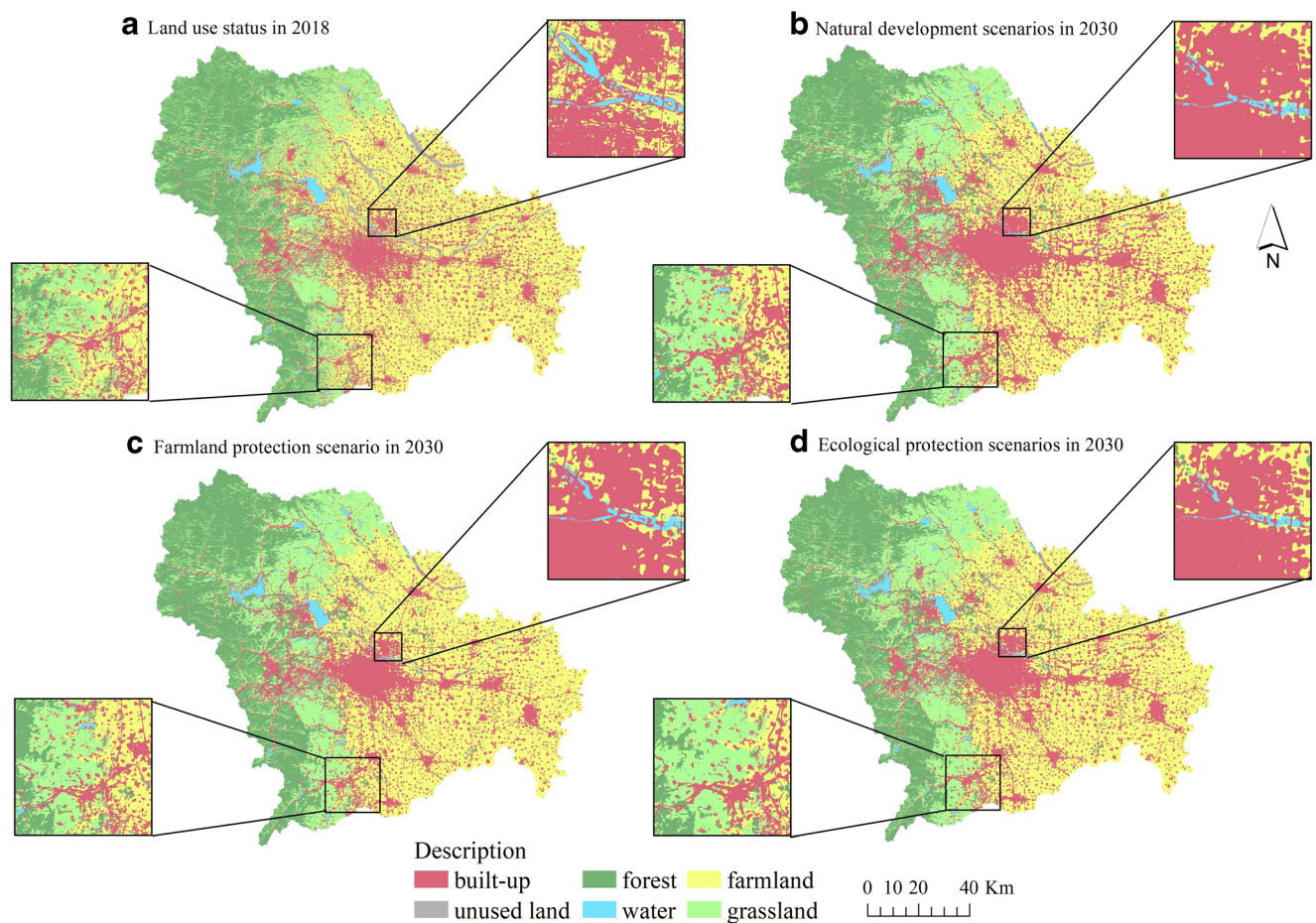


Fig. 4 Land use change simulation of Shijiazhuang city in 2030 under different scenarios

grid to calculate the ESV of each grid. The spatial distribution map of ESV in Shijiazhuang in 2030 in 2018 and multiple scenarios was produced, and the natural break point method was used to divide it into 6 grades from low to high, with the lowest grade I and the highest grade VI (see Fig. 6). From the perspective of the spatial distribution of ESV in Shijiazhuang in 2018, the overall ESV in Shijiazhuang show a trend of high in the west and low in the east, which is consistent with the spatial distribution of altitude in the study area. The main reason is that the elevation in the west of Shijiazhuang is higher, with forest and grassland as the main land types, and the ESV is higher; the east is the plain, with a lower altitude, and the main land types are farmland and built-up, and the ESV is lower. The ecosystem service value grade VI is mainly distributed in Gangnan Reservoir and Huangbizhuang Reservoir.

The spatial distribution map of ESV in the natural development scenario of Shijiazhuang in 2030 is based on the simulation of the land use type development law in 2008 and 2018 without any intervention. Therefore, comparing the spatial changes of the two phases of ESV will provide scientific support for the future adjustment of land use strategy in Shijiazhuang. Compared with 2018, the ESV of Shijiazhuang decreased significantly in the natural development scenario of 2030, and the ESV in the six districts of Shijiazhuang, Zhao County, Zhengding County, Gaocheng District, Jinzhou City, and Xinji City shifted from level II to level I. In Lingshou County, Xingtang County, and Pingshan County in the northwest of Shijiazhuang, ESV generally showed an upward trend (Fig. 5).

By comparing and analyzing the spatial distribution maps of ESV under three scenarios in Shijiazhuang in 2030, it was found that the overall ESV of farmland protection scenarios and ecological protection scenarios is significantly better than natural development scenarios. Since the ecological protection scenario

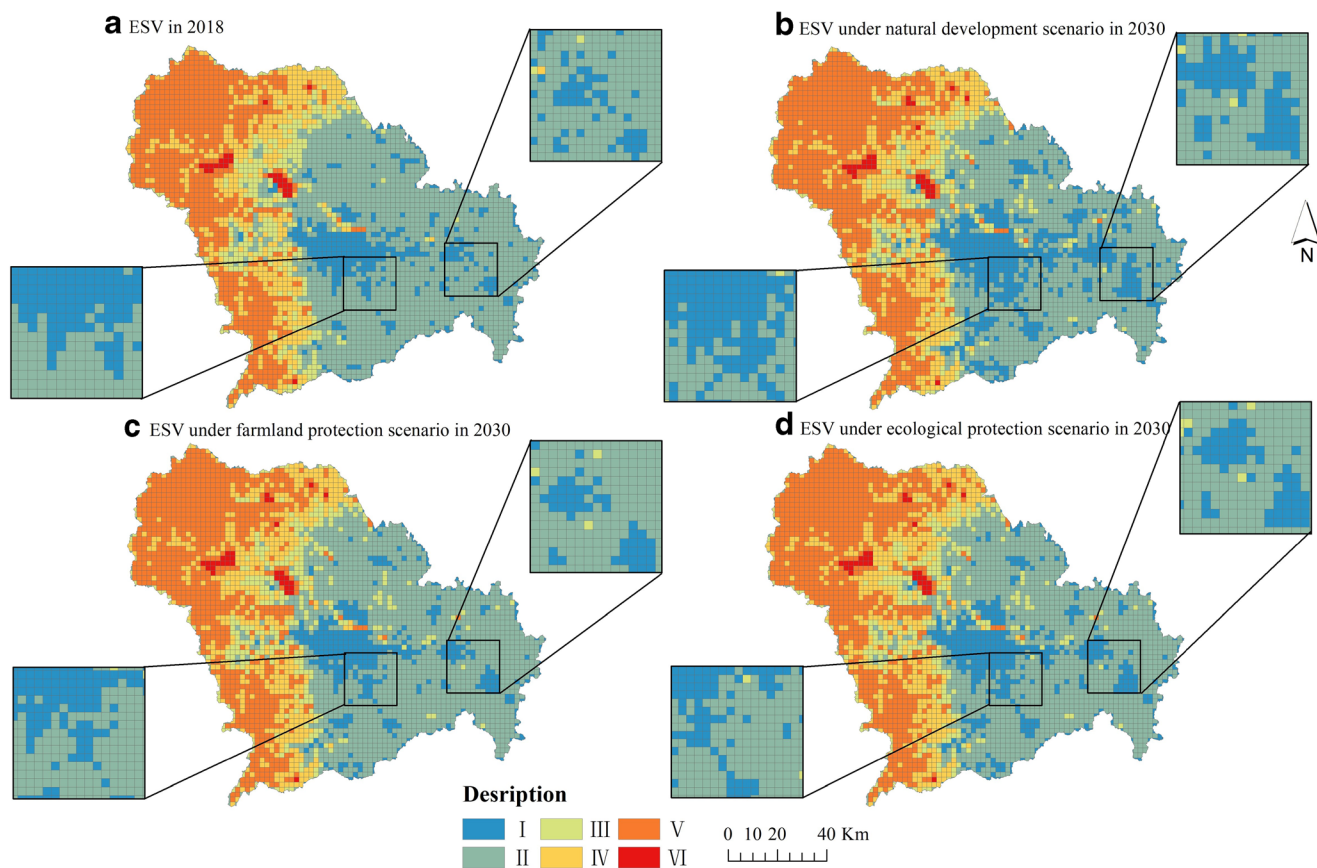
and the farmland protection scenario strictly restrict the conversion of farmland to built-up, the situation of grade I in the east is significantly reduced (Fig. 5). The ESV in the Shijiazhuang Western Ecological Protection Scenario is slightly better than the farmland protection scenario. This is mainly because the transfer of forest and grassland to other types of land use has decreased, and the water area has increased significantly.

### Analysis of hot spots in Shijiazhuang ESV under various situations

In order to reflect the spatial aggregation of high and low values of ecosystem services, a grid unit of 2km×2km was selected. Based on ArcGis software, the hot spot analysis (Getis-Ord Gi\*) in the spatial statistical tool was used to obtain the hot and cold areas of the ecosystem service value of Shijiazhuang, as shown in Fig. 6. As can be seen from Fig. 6, the distribution of hot and cold spots in the ESV value of Shijiazhuang in 2018 is relatively large. Hot spots are mainly concentrated in the northwest and southwest, and 99% confidence hot spots are concentrated in Gangnan Reservoir and Huangbizhuang Reservoir. The cold spot areas are distributed in the urban areas of Shijiazhuang, Gaocheng, Jinzhou, Luancheng, and eastern Xinji, and the cold spot areas of downtown in Shijiazhuang are the largest. Compared with 2018, the overall characteristics of the three development scenarios in 2030 are as follows: the distribution range of hot spots is reduced, and the distribution range of cold spots is expanded. Specific to each scenario, under the natural development scenario, 99% confidence hot spots in Lingshou County and Xingtang County of Shijiazhuang City have increased significantly, mainly due to the conversion of grasslands and woodlands into water areas, leading to an increase in ESV. Due to the accelerated expansion of built-up in Pingshan County and Jingxing County in the northwest and Zhanhuang County in

**Table 6** The service value of each land ecosystem under three development scenarios will be simulated in 2030 (units: 10<sup>8</sup> yuan)

| Land use type                  |                | Farmland | Forestland | Grassland | Built-up | Water | Unused land | Total  |
|--------------------------------|----------------|----------|------------|-----------|----------|-------|-------------|--------|
| 2018a                          | ESV            | 42.95    | 149.91     | 79.01     | 0.00     | 40.61 | 0.02        | 315.51 |
|                                | Proportion (%) | 13.74    | 47.97      | 25.28     | 0.00     | 12.99 | 0.00        | 100    |
| Natural development scenario   | ESV            | 36.17    | 146.09     | 93.40     | 0.00     | 55.44 | 0.01        | 331.11 |
|                                | Proportion (%) | 10.92    | 44.12      | 28.21     | 0.00     | 16.74 | 0.00        | 100    |
| Farmland protection scenario   | ESV            | 41.04    | 146.09     | 93.40     | 0.00     | 56.16 | 0.01        | 336.70 |
|                                | Proportion (%) | 12.19    | 43.39      | 27.74     | 0.00     | 16.68 | 0.00        | 100    |
| Ecological protection scenario | ESV            | 38.95    | 147.29     | 96.83     | 0.00     | 55.83 | 0.01        | 338.91 |
|                                | Proportion (%) | 11.49    | 43.46      | 28.57     | 0.00     | 16.47 | 0.00        | 100    |



**Fig. 5** Spatial distribution of ESV in Shijiazhuang in 2030 under different circumstances

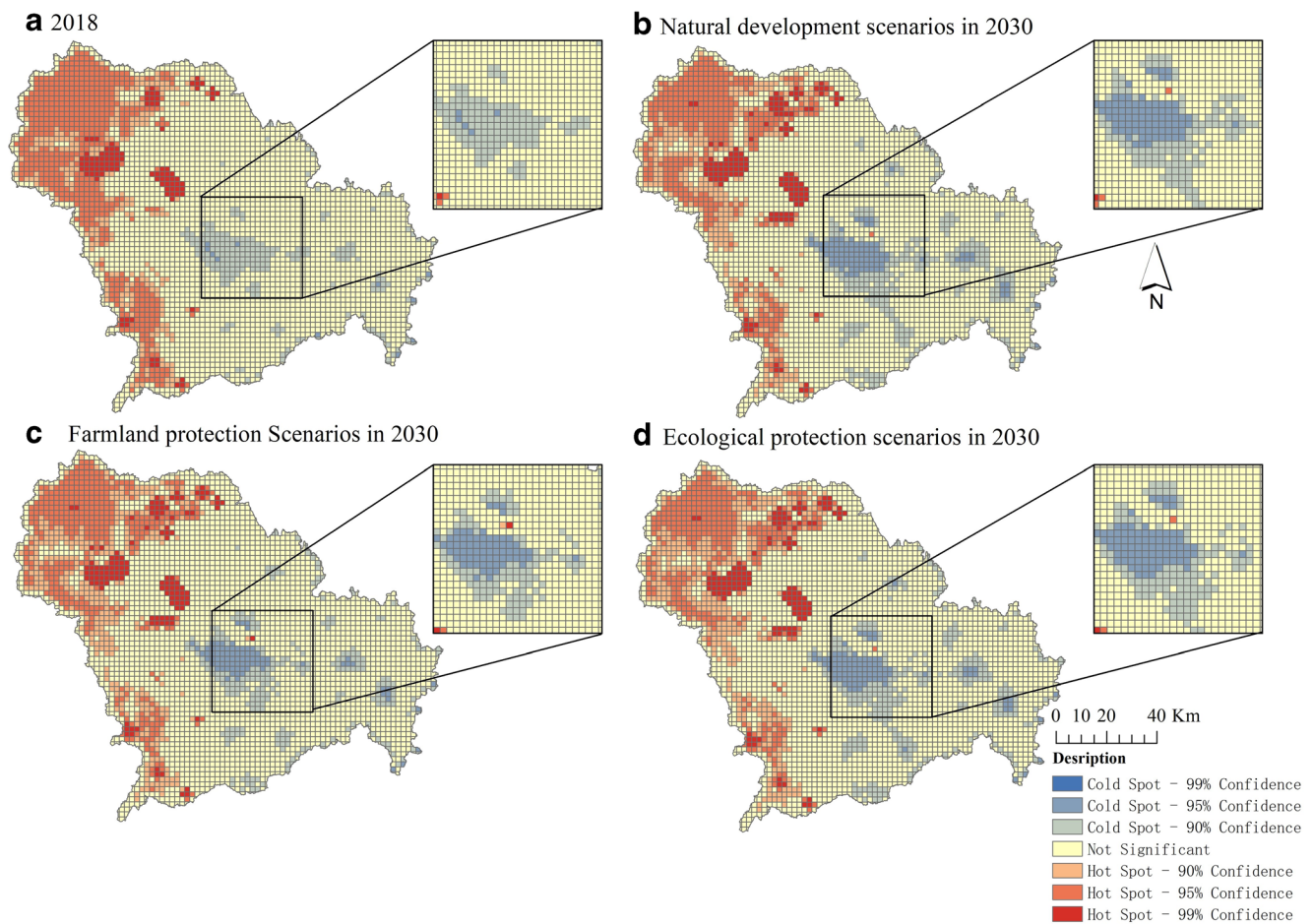
the southwest in recent years, the ESV has shown a downward trend and the hot spot area has shrunk significantly. The scope of cold spot area in Shijiazhuang has expanded, and the degree of agglomeration is getting higher and higher, and it has started to connect with Gaocheng District and Luancheng District. Under the natural development scenario, Shijiazhuang still maintains a rapid urbanization process, and a large amount of farmland and ecological land are occupied by built-up, resulting in an obvious decline in ESV. This is especially obvious in the eastern part where the terrain is flat and there are many farmlands. Under the protection of farmland, the changes in the hot spots in the west of Shijiazhuang are similar to the natural development scenario. Compared with 2018, the cold spots in the east have a deeper agglomeration, and the cold spots show an expansion trend, but the expansion rate is slow. In this scenario, due to strict restrictions on the amount of farmland, only a small amount of farmland is converted to other land use types and ESV changes are not obvious, so the expansion rate of the cold spot area is slower. Under the ecological protection scenario, the hot spot areas in the northwest and southwest are gradually shrinking, and the cold spot areas in the east are gradually expanding.

Comparing the three scenarios in 2030, it was found that the range of the cold spot area is as follows: natural development scenario > ecological protection scenario > arable land protection

scenario. There are many farmlands in the east of Shijiazhuang. Under natural development scenarios, the farmland around the city is occupied by built-up, which leads to the formation of cold spot areas with ESV lower than the surrounding ESV. The area of cold spot areas is continuously expanding and the degree of aggregation is deepening. The farmland protection scenario is to strictly control the transfer of farmland, and the expansion of built-up slows down. In the ecological protection scenario, due to the key restrictions on the transfer of forest and grassland, the farmland in the east is still occupied by built-up. However, compared with the natural development scenario, the amount of farmland transferred is still small. The hot spots in the three scenarios are concentrated in the northwest and southwest of Shijiazhuang. These areas have higher altitudes, larger slopes, and widespread woodlands and grasslands, which are very likely to form hot spots.

## Discussions

In this study, under the background of land use change caused by urban expansion, the CA-Markov model was used to simulate the land use change status of Shijiazhuang in 2030 under three scenarios. The ESV of Shijiazhuang was evaluated and the spatial distribution



**Fig. 6** Distribution of ESV hot spots in Shijiazhuang in 2030 under different conditions

and agglomeration characteristics were analyzed based on this. From the results, the rapid expansion of built-up land in Shijiazhuang leads to the decline of ESV, especially in the surrounding areas of the main urban area, indicating that land use change and urban expansion are the key factors causing the decline of ESV. Farmland protection and ecological protection scenarios can improve the ESV of the region, reflect the change trend of regional ESV and the change of regional ecological security to a certain extent, and provide reference for optimizing the land spatial pattern and high-quality development in the region. Shijiazhuang’s urbanization level will continue to rise in the future (Liu et al. 2018). The period of rapid expansion of construction land has not completely ended. Moreover, Shijiazhuang is located in North China, where the carrying capacity of resources and environment is weak, air quality is in urgent need of improvement, and water resources are scarce. Therefore, it is urgent to improve the ecosystem service function of Shijiazhuang. Therefore, Shijiazhuang should formulate corresponding land space planning and protection measures, including delimiting urban development boundary and ecological red line, and constructing ecological security pattern. Should strictly control the scale of

urban built-up land, enhance the construction of urban internal ecological space by improving land use efficiency, and realize the coordinated development of urban high-quality development and ecological protection, so as to improve the ecosystem service function of Shijiazhuang City.

### Conclusions

Based on the land use change, this study studied the ecosystem service value of Shijiazhuang. The main conclusions are as follows:

1. From 1988 to 2018, the rapid urbanization process of Shijiazhuang city led to the expansion of urban built-up land, occupying a large number of ecological land such as cultivated land, woodland and grassland, aggravating the contradiction between man and land, damaging the urban ecological environment, and even threatening the urban ecological security. In the past 30 years, the ecosystem service value of Shijiazhuang City showed a trend of first decreasing and then increasing, and the overall pattern was high in the west and low in the east.

2. After simulating three scenarios in Shijiazhuang in 2030, it was found that under different scenarios, the ESV of land use pattern in Shijiazhuang was different. Under the natural development scenario, due to the rapid expansion of the city, the farmland is seriously affected; under the protection of farmland, the rate of reduction of farmland has decreased, and the expansion rate of built-up is more reasonable; under the ecological protection scenario, forest, grassland and water area are strictly restricted. Except for the small fluctuation of forest area, the area of grassland and water area has increased significantly. ESV is affected by LUC and changes with the change of land use pattern.
3. Distribution of ESV hot spots in different situations. In general, the hot spots and cold spots of the ESV value in Shijiazhuang are widely distributed and the degree of agglomeration continues to increase.

To sum up, although the process of urbanization will lead to the reduction of land use types with high ecosystem service value and the corresponding decline of ecosystem services, the formulation of corresponding land use policies, the control of urban sprawl, and the optimization of land use pattern can effectively enhance the value of urban ecosystem services and ensure urban ecological security.

**Availability of data and materials** The datasets used or analyzed during the current study are available from the corresponding author on reasonable request.

**Authors' contributions** Xing Gao and Chenxi Li contributed to the conception of the study; Xing Gao, Jie Wang, and Chenxi Li performed the experiment; Xing Gao and Weining Shen contributed significantly to analysis and manuscript preparation; Zhaoying Song performed the data analyses and wrote the manuscript; Chengjing Nie and Xueru Zhang helped perform the analysis with constructive discussions.

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## Declarations

**Ethical approval** Not applicable

**Consent to participate** Not applicable.

**Consent to publish** Not applicable.

**Conflict of interest** The authors declare no competing interests.

## References

- Bagstad KJ, Johnson GW, Voigt B, Villa F (2013) Spatial dynamics of ecosystem service flows: a comprehensive approach to quantifying actual services. *Ecosyst Serv* 4:117–125
- Castro AJ, Opez BM, Opez EL, Plieninger T, Cabello J (2015) Do protected areas networks ensure the supply of ecosystem services? Spatial patterns of two nature reserve systems in semi-arid Spain. *Appl Geogr* 60:1–9
- Costanza R, D'Arge R, Groot RD, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill RV, Paruelo J, Raskin RG, Sutton P, Van den Belt M (1997) The value of the world's ecosystem services and natural capital. *Nature* 387:253–260
- Costanza R, Groot RD, Sutton P, Van der Ploeg S, Anderson SJ, Kubiszewski L, Farber S, Kerry Turner R (2014) Changes in the global value of ecosystem services. *Glob Environ Chang* 26(1):152–158
- Daily GC (2000) The value of nature and the nature of value. *Science* 289:395–396
- Du Y, Shui W, Sun XR, Yang HF, Zheng JY (2019) Scenario simulation of ecosystem service trade-offs in bay cities: A case study in Quanzhou, Fujian Province, China. *Chin J Appl Ecol* 30(12):4293–4302
- Egoh B, Rouget M, Reyers B, Knight AT, Cowling RM, van Jaarsveld AS, Welz A (2007) Integrating ecosystem services into conservation assessment: A review. *Ecol Econ* 63:714–721
- Egoh BN, Reyers B, Rouget M, Richardson DM (2011) Identifying priority areas for ecosystem service management in South African grasslands. *J Environ Manag* 92:1642–1650
- Eigenbrod BVA, Davies HN, Heinemeyer A, Armsworth PR, Gaston KJ (2011) The impact of projected increases in urbanization on services. *Proc Biol Sci* 278(1722):3201–3208
- Estoque RC, Murayama Y (2012) Examining the potential impact of land use/cover changes on the ecosystem services of Baguio city, the Philippines: Ascenario-based analysis. *Appl Geogr* 35:316–326
- Estoque RC, Murayama Y (2015) Intensity and spatial pattern of urban land changes in the megacities of Southeast Asia. *Land Use Policy* 48:213–222
- Fu BJ, Zhang LW (2014) Land-use change and ecosystem services: concepts, methods and progress. *Prog Geogr* 33(4):441–446
- Gómez-Baggethun E, Barton DN (2013) Classifying and valuing ecosystem services for urban planning. *Ecol Econ* 86:235–245
- Han J, Hayashi Y, Cao X, Lmura H (2009) Application of an integrated system dynamics and cellular automata model for urban growth assessment: a case study of Shanghai, China. *Landsc Urban Plan* 91(3):133–141
- Hang HQ, Hu Y, Wang QX (2015) Evaluation of land use efficiency in three major urban agglomerations of China in 2001–2012. *Sci Geogr Sin* 35(09):1095–1100
- Hao RF, Yu DY, Liu YP, Qiao JM, Wang X, Du JS (2017) Impacts of changes in climate and landscape pattern on ecosystem services. *Sci Total Environ* 579:718–728
- He BJ, Zhao DX, Zhu J, Darko A, Gou ZH (2018) Promoting and implementing urban sustainability in China: An integration of sustainable initiatives at different urban scales. *Habitat Int* 82:83–93
- He BJ, Wang J, Liu H, Ulpiani G (2021) Localized synergies between heat waves and urban heat islands: Implications on human thermal comfort and urban heat management. *Environ Res* 193:110584
- Himes CA, Pendleton L, Atiyah P (2018) Valuing ecosystem services from blue forests: a systematic review of the valuation of salt marshes, sea grass beds and mangrove forests. *Ecosyst Serv* 30:36–48

- Huang DX, Wu YJ, She SX (2017) A study on symbiosis evolution of value co-creation unit in service ecosystem. *Ecol Econ* 33(07):121–126 +139
- Huang LS, Wang B, Niu X, Gao P, Song QF (2019) Changes in ecosystem services and an analysis of driving factors for China's Natural Forest Conservation Program. *Ecol Evol* 9(7):3700–3716
- Jiang GH, Zhang FR, Qin J, Zhang L, Gong P (2006) Relationship between distribution changes of rural residential land and environment in mountainous areas of Beijing. *Transact Chin Soc Agric Eng* 11: 85–92
- Jiang C, Nath R, Labzovskii L, Wang D (2018) Integrating ecosystem services into effectiveness assessment of ecological restoration program in Northern China's arid areas: Insights from the Beijing-Tianjin Sandstorm Source Region. *Land Use Policy* 75:201–214
- Jiang W, Fu B, Lü Y (2020) Assessing Impacts of Land Use/Land Cover Conversion on Changes in Ecosystem Services Value on the Loess Plateau, China. *Sustainability* 12(17):7128
- Karki S, Thandar AM, Uddin K, Tun S, Aye WM, Aryal K, Kandel P, Chettri N (2018) Impact of land use land cover change on ecosystem services: a comparative analysis on observed data and people's perception in Inle Lake, Myanmar. *Environ Syst Res* 7(1):25
- Kertész Á, Nagy LA, Balázs B (2019) Effect of land use change on ecosystem services in Lake Balaton Catchment. *Land Use Policy* 80:430–438
- Kremer P, Hamstead ZA, McPhearson T (2016) The value of urban ecosystem services in New York City: A spatially explicit multicriteria analysis of landscape scale valuation scenarios. *Environ Sci Pol* 62:57–68
- Kubiszewski I, Costanza R, Anderson S, Sutton P (2017) The future value of ecosystem services: Global scenarios and national implications. *Ecosyst Serv* 26:289–301
- Lautenbach S, Kugel C, Lausch A, Seppelt R (2011) Analysis of historic changes in regional ecosystem service provisioning using land use data. *Ecol Indic* 11:676–687
- Lei JR, Chen ZZ, Chen XH, Li YL, Wu TT (2020) Spatio-temporal changes of land use and ecosystem services value in Hainan Island from 1980 to 2018. *Acta Ecol Sin* 40(14):4760–4773
- Li C, Gao X, He B, Wu J, Wu K (2019a) Coupling Coordination Relationships between Urban-industrial Land Use Efficiency and Accessibility of Highway Networks: Evidence from Beijing-Tianjin-Hebei Urban Agglomeration, China. *Sustainability* 11:1446
- Li C, Gao X, Wu J, Wu K (2019b) Demand prediction and regulation zoning of urban-industrial land: Evidence from Beijing-Tianjin-Hebei Urban Agglomeration, China. *Environ Monit Assess* 191(7):412
- Liu XY, Kuang WH (2019) Spatio-Temporal Trajectories of Urban Land Use Change During 1980–2015 and Future Scenario Simulation in Beijing-Tianjin-Hebei Urban Agglomeration. *Econ Geogr* 39(03): 187–194 +200
- Liu YQ, Liao LW, Long HL (2015) Effects of land use transitions on ecosystem services value: A case study of Hunan province. *Geogr Res* 34(04):691–700
- Liu JH, Li WF, Zhou WQ, Han LJ, Qian GY (2018) Scenario simulation balancing multiple objectives for optimal land use allocation of the Beijing-Tianjin-Hebei megaregion. *Acta Ecol Sin* 38(12):4341–4350
- Liu ZW, Yin D, Huang QX, He CY, Xue F (2019) Research and application progress of ecosystem services in land use planning: Bibliometric and textual analysis. *Prog Geogr* 38(2):236–247
- Mario VB, Caruana J, Zammit A (2018) Assessing the capacity and flow of ecosystem services in multifunctional landscapes: Evidence of a rural-urban gradient in a Mediterranean small island state. *Land Use Policy* 75:711–725
- Masek JG, Lindsay F, Goward SN (2000) Dynamics of Urban Growth in the Washington DC Metropolitan Area 1973–1996 from Land Sat Observations. *Int J Remote Sens* 21(18):3473–3486
- Millennium Ecosystem Assessment (2005) *Ecosystems and Human Well-being: Current State and Trends*. Island Press, Washington D C, pp 37–39
- Niemelä J, Saarela SR, Sderman T, Kopperoinen L, Yli-Pelkonen V, Vre S, Kotze DJ (2010) Using the ecosystem services approach for better planning and conservation of urban green spaces: a Finland case study. *Biodivers Conserv* 19(11):3225–3243
- Ouyang X, He QY, Zhu X (2020) Simulation of Impacts of Urban Agglomeration Land Use Change on Ecosystem Services Value under Multi-Scenarios: Case Study in Changsha-Zhuzhou-Xiangtan Urban Agglomeration. *Econ Geogr* 40(01):93–102
- Shui W, Du Y, Wang YN, Yang HF, Fu Y, Fan BX, Huang MY (2019) Spatiotemporal dynamics and scenarios simulation of trade-offs between ecosystem services in Min Delta urban agglomeration. *Acta Ecol Sin* 39(14):5188–5197
- Song X (2018) Global estimates of ecosystem service value and change: Taking into account uncertainties in Satellite-based land cover data. *Ecol Econ* 143:227–235
- Srikanta S, Zhang Q, Joshi PK, Sutton PC, Keesstra S, Roy PS, Pilla F, Basu B, Wang Y, Jha S, Paul SK, Sen S (2020) Examining effects of climate change and land use dynamic on biophysical and economic values of ecosystem services of a natural reserve region. *J Clean Prod* 257:120424
- Vallet A, Locatelli B, Levrel H, Wunder S, Seppelt R, Scholes RJ, Oszward J (2018) Relationships between ecosystem services: comparing methods for assessing tradeoffs and synergies. *Ecol Econ* 150:96–106
- Wang YS, Yu XX, He KN, Li QY, Zhang YS, Song SM (2011) Dynamic simulation of land use change in Jihe watershed based on CA-Markov model. *Transact Chin Soc Agric Eng* 27(12):330–336 +442
- Wang JL, Wu GP, Fan QY, Cui JT (2015) Change and prediction of land use in Linyi City, Shandong Province, based on CA-Markov model. *Res Soil Water Conserv* 22(01):212–216
- Wang X, Ma BW, Li D, Chen KL, Yao HS (2020) Multi-scenario simulation and prediction of ecological space in Hubei province based on FLUS model. *J Nat Resour* 35(01):230–242
- Woldeyohannes A, Cotter M, Biru WD, Kelboro G (2020) Assessing changes in ecosystem service values over 1985–2050 in response to land use and land cover dynamics in Abaya-Chamo Basin, Southern Ethiopia. *Land* 9(2):37
- Wondie A (2018) Ecological conditions and ecosystem services of wetlands in the Lake Tana Area, Ethiopia. *Ecohydrol Hydrobiol* 18(2): 231–244
- Wu K, Li YC (2019) Research progress of urban land use and its ecosystem services in the context of urban shrinkage. *J Nat Resour* 34(05): 1121–1134
- Xie GD, Lu CX, Cheng SK (2001) Progress in evaluating the global ecosystem services. *Resour Sci* 6:5–9
- Xie GD, Lu CX, Leng YF, Zheng D, Li SC (2003) Ecological assets valuation of the Tibetan Plateau. *J Nat Resour* 2:189–196
- Xie GD, Zhen L, Lu CX, Xiao Y, Chen C (2008) Expert knowledge based valuation method of ecosystem services in China. *J Nat Resour* 5:911–919
- Xie GD, Zhang CX, Zhang LX, Chen WH, Li SM (2015) Improvement of the evaluation method for ecosystem service value based on per unit area. *J Nat Resour* 30(08):1243–1254
- Xu C, Jiang WY, Huang QY, Wang YT (2020) Ecosystem services response to rural-urban transitions in coastal and island cities: A comparison between Shenzhen and Hong Kong, China. *J Clean Prod* 260:121033
- Yang GF, Ge Y, Xue H, Yang W, Shi Y, Peng CH, Du YY, Fan X, Ren Y, Chang J (2015) Using ecosystem service bundles to detect trade-offs and synergies across urban-rural complexes. *Landsc Urban Plan* 136:110–121

- Yang J, Sun J, Ge Q, Li X (2017) Assessing the impacts of urbanization-associated green space on urban land surface temperature: A case study of Dalian, China. *Urban For Urban Green* 22:1–10
- Yang K, Yu Z, Yi L, Yang Y, Lei Z, Zhou X (2018) Spatial and temporal variations in the relationship between lake water surface temperatures and water quality-A case study of Dianchi Lake. *Sci Total Environ* 624:859–871
- Yang K, Yu ZY, Luo Y, Shang CX, Zhou XL (2019) Spatial-temporal variation of lake surface water temperature and its driving factors in Yunnan-Guizhou Plateau. *Water Resour Res* 55:4688–4703
- Yang J, Luo X, Jin C, Xiao X, Xia JC (2020a) Spatiotemporal patterns of vegetation phenology along the urban–rural gradient in Coastal Dalian, China. *Urban For Urban Green* 54:126784
- Yang K, Yu ZY, Luo Y (2020b) Analysis on driving factors of lake surface water temperature for major lakes in Yunnan-Guizhou Plateau. *Water Res* 184:116018
- Yue DX, Yang C, Jiang BY, Guo JJXXF (2019) Spatio-temporal pattern prediction of the biocapacity in the Shiyang River Basin on the basis of the CA-Markov model. *Acta Ecol Sin* 39(06):1993–2003
- Zhang HY, Fan JW, Gao W, Zhong HP, Harris W, Gong GL, Zhang YX (2018) Changes in multiple ecosystem services between 2000 and 2013 and their driving factors in the Grazing Withdrawal Program, China. *Ecol Eng* 116:67–79
- Zhao D, Arshad M, Li N, Triantafyllis J (2021) Predicting soil physical and chemical properties using vis-NIR in Australian cotton areas. *Catena* 196:104938

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