LAND-USE CHANGE AND ECOSYSTEM SERVICE TRADE-OFF IN THE KARST-COASTAL ZONE OF SOUTHWEST GUANGXI, CHINA

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Abstract. Based on four periods of land use data in 2005, 2010, 2015 and 2020, we analyzed the spatial and temporal variation characteristics of land use and ecosystem services in the karst-coastal zone of southwest Guangxi, China, and used the InVEST model and scenario simulation method to assess the supply capacity of four ecosystem services, namely habitat quality, soil conservation, water yield and carbon storage, in the study area, and to explore the spatial and temporal trade-off or synergistic relationships of each ecosystem service. The research indicates: (1) Built-up land, farmland and forestland changed most significantly from 2005 to 2020, with the conversion of farmland to built-up land being the most dramatic, while forestland was the largest source of increase in farmland area.(2) The spatial distribution pattern of ecosystem services in the study area is not very variable, with high value areas for ecosystem services concentrated in nature reserves, forest parks and forestry management areas, and low value areas concentrated in the Left River-Right River-Yong River valleys and the coastal zone of Beibu Gulf.(3) Ecosystems in the study area are dominated by multiple service types, with high importance areas for integrated ecosystem services occurring mostly on forestland types. While general areas have weaker ecosystem services or tend to have a single type of ecosystem service, and occur mostly on land types such as built-up land and farmland. (4) The supply capacity of all ecosystem services in the study area decreases under the natural development scenario and the urban-rural expansion scenario, while the supply capacity of all ecosystem services increases under the ecological conservation scenario.
Keywords: *InVEST model, multi-Scenario, land use, ecosystem service trade-off and synergy, karst-coastal zone*

Introduction

Land use change and ecosystem services are closely related, and land use patterns and intensities affect various ecological processes and the provision of ecosystem services (Costanza et al., 1997; Lautenbach et al., 2011; Wu and Li, 2019). An in-depth exploration of land use change, the spatial and temporal evolution patterns of ecosystem services, and the trade-off and synergistic relationships among the services are not only a new direction for research in sustainable development science, ecology and geography in China and abroad, but also an important part of national ecological construction and sustainable development.

Foreign scholars have pioneered research on land use change, ecosystem service assessment and its trade-off and synergies, and to date, their theories and methods and model applications have been continuously improved and made great progress, which has served as a good reference basis for related research in China. In the study of land use change, ecosystem service assessment and its trade-off and synergistic relationships in China and abroad, research techniques are becoming more and more mature, research directions are expanding, research systems cover grasslands (Bai et al., 2021; Li et al., 2021), forests (Wang and Fu, 2013; Wang et al., 2021), cities (Zhang et al., 2022) and other aspects, research areas include basins (Forio et al., 2020; Yuan et al., 2022), hills (Bai et al., 2021; Muhati, 2022), plateaus (Feng et al., 2020) and other topographical landscapes, research time levels are expanding from static analysis to dynamic analysis, research content is mainly focused on the study of trade-off and synergistic relationships of ecosystem services (Nemec and Raudsepp-Hearne, 2013), the study of spatial heterogeneity of ecosystem services (Turner et al., 2013), and the optimization of ecosystem service assessment methods (Brown et al., 2007; Bagstad et al., 2013; Nemec and Raudsepp-Hearne, 2013), etc., to continuously improve the practicality and application of research results. However, most of the current studies related to the trade-off and synergistic relationships between land use change and ecosystem services are based on administrative regions (Nation, Province, city and county) (Butler et al., 2013; Zhao and Li, 2020), watersheds (Yang et al., 2021), or a specific region (Bohensky et al., 2006) as the research unit. Comprehensive studies on representative areas such as karst areas and coastal areas are still lacking, and no experts and scholars have yet carried out relevant studies with the research objects of karst-coastal zone in southwest Guangxi.

Since the reform and opening up, the development model with economic construction as the primary goal has greatly promoted China's economic and social construction, but a series of environmental problems accumulated over a long period of time have seriously restricted the further development of our society. In the context of the new era, General Secretary Xi Jinping, based on China's national conditions and the overall national strategy, put forward the "green development concept" at the fifth plenary session of the 18th Communist Party of China Central Committee, incorporated the construction of ecological civilization into the national development strategy at the 18th Communist Party of China National Congress, and proposed building a beautiful China at the 19th Communist Party of China National Congress, paying more attention to the protection and construction of ecological environment. In 2017, General Secretary Xi Jinping put forward the requirement of "Guangxi's ecological advantages are golden" to Guangxi, which stands on the overall development of the Communist Party of China and the country, puts ecological protection in the first place, and opens up the green development avenue with Guangxi characteristics. The study area of this paper is a typical space formed by the conjugation of karst mountains, watershed and Beibu Gulf Coastal Zone in Guangxi. In this special space, many important national and regional development strategies are gathered, and it is an important corridor of China-ASEAN Free Trade Area and "One Belt, One Road", as well as the intersection of Guangxi Beibu Gulf Economic Zone, China (Guangxi) Pilot Free Trade Zone and the New International Land-Sea Trade Corridor. Therefore, the harmonization of regional economic construction and ecological protection in a region with both unique natural attributes and important social attributes is in line with national and regional strategic development concepts.

Based on this, this paper takes the karst-coastal zone in southwest Guangxi as the research object, analyzes the spatial and temporal land use change characteristics of the study area from 2005 to 2020 with the help of remote sensing images, assesses the supply capacity of four ecosystem services, namely habitat quality, soil conservation, water yield and carbon storage, based on the InVEST model and scenario simulation method, and explores the spatial and temporal trade-off or synergistic relationships of each ecosystem service, in order to provide a reference for coordinating regional ecological conservation and sustainable socio-economic development.

Materials and methods

Study area

The study area is located in the southwestern part of Guangxi Province (*Fig. 1*), China, ranging from 20°54’ 8” N–25°6’ 6” N and 104°26’ 47” E–109°51’ 15” E. It includes six cities of Nanning, Baise, Fangchenggang, Chongzuo, Qinzhou and Beihai, with a total area of about 95538 km^2, accounting for 40.20% of the total land area of Guangxi. The study area is adjacent to Yunnan Province and Guizhou Province in the northwest, borders with Vietnam in the west, and faces Beibu Gulf in the south. It is located in a top-down inclined transition zone from the Yunnan-Kweichow Plateau to the coastal zone of Beibu Gulf, and there are many rivers in the whole zone, such as Right River, Left River, Yong River, Qin River, Fangcheng River, Maoling River, Beilun River, Nanliu River, etc. It has a special geographical position of being coastal, along the border and along the river. The study area has abundant precipitation, the average annual precipitation is above 1600 mm, and there are vegetation types such as broad-leaved forest, irrigation grass forest and mangrove forest, and there are various soil types, mainly distributed with brick red loam, red loam, purple soil and limestone soil. The topography, climate, vegetation and other natural elements, population density, economic and social development level, and land use pattern and intensity of the study area show transitional structural characteristics.

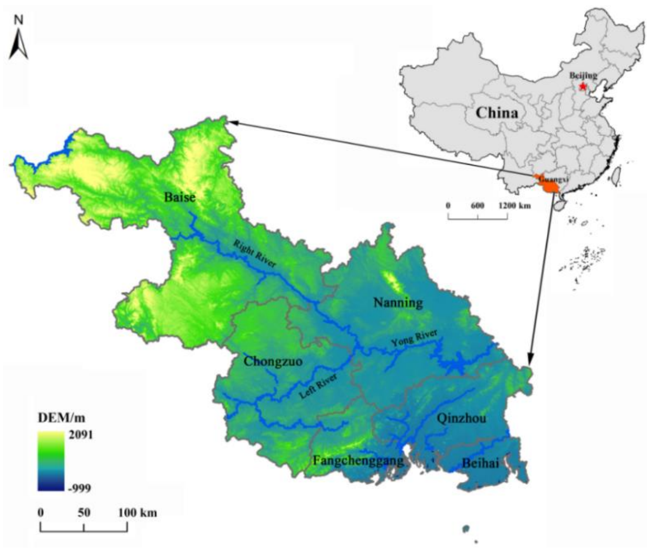

Figure 1. *Study area*

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Data source

The data mainly include land use, soil, meteorology, DEM and other basic geographic data, and the specific data parameters are shown in *Table 1*. the resolution of the raster data used in the study, such as land use, DEM and meteorology, is uniformly processed to 30 m.

Table 1. *Data sources and data processing instructions*

Data type	Data description	Data processing instructions	Data source
Land use raster data	Land use classification maps for 2005, 2010, 2015, 2020. data spatial resolution of 30 m	Based on ArcGIS software, the land use data of each year was reclassified into farmland, forestland, grassland, water body, built-up land and unused land	Data Center for Resources and Environment, Chinese Academy of Sciences (http://www.resdc.cn/data)
Soil raster data	Soil data include properties such as sand, meal, clay, bulk weight, organic matter, etc., data spatial resolution of 1000 m	Soil dataset is processed by point to raster and raster cropping with ArcGIS software to obtain soil property data of the study area	Chinese Soil Dataset of the World Soil Database (HWSD)
Meteorological data	Meteorological data including temperature, precipitation, total solar radiation and other station data	Data from 13 national meteorological stations in the study area were selected, and then spatially interpolated for temperature, precipitation, and total solar radiation to obtain raster meteorological data	China Meteorological Science Data Sharing Service Network (http://cdc.nmic.cn/)
DEM	Data spatial resolution of 30 m	Raster cropping of DEM data with the help of ArcGIS software to obtain DEM data of the study area	Geospatial Data Cloud (http://www.gscloud.cn/)
Other basic geographic data	Administrative division of the study area (including city, county and township administrative division units), roads, water systems, topographic maps	— —	91 wei map

Study methods

Ecosystem services assessment methods

Based on the InVEST model and ArcGIS 10.7 software, the four ecosystem service functions of soil conservation, water yield, carbon storage and habitat quality in the study area were quantitatively assessed in 2005, 2010, 2015 and 2020, and their spatial and temporal variation characteristics were revealed. Calculations were performed as follows.

(1) Soil conservation

Soil conservation is obtained by subtracting the actual soil loss from the potential soil erosion and is calculated as follows (Sharp et al., 2018):

$$RKLS = R \times K \times LS \quad \text{(Eq.1)}$$

$$USLE = R \times K \times LS \times P \times C \quad \text{(Eq.2)}$$

$$SD = RKLS\text{-}USLE \quad \text{(Eq.3)}$$

where: *SD* is the soil conservation amount ($t \cdot hm^{-2} \cdot a^{-1}$); *RKLS* is the potential soil erosion amount ($t \cdot hm^{-2} \cdot a^{-1}$); *USLE* is the actual soil erosion amount ($t \cdot hm^{-2} \cdot a^{-1}$); *R* is the rainfall erosion force factor ($MJ \cdot mm \cdot hm^{-2} \cdot hm^{-1} \cdot a^{-1}$); *K* is the soil erodibility factor

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($t\cdot hm^{-2}\cdot h\cdot hm^{-2}\cdot MJ^{-1}\cdot mm^{-1}$); *LS*, *C* and *P* are denoted as the slope and slope length factor, vegetation cover and management factor, and engineering measures factor, respectively.

(2) Water yield

The water yield is the difference between the rainfall minus the evapotranspiration for each grid cell (Clerici et al., 2019), and the water yield model is calculated as follows:

$$Y_{xj} = \left(1 - \frac{AET_{xj}}{P_x}\right) \times P_x \quad \text{(Eq.4)}$$

$$\frac{AET_{xj}}{P_x} = \frac{1+\ \omega_x R_{xj}}{1+\ \omega_x R_{xj} + 1/R_{xj}} \quad \text{(Eq.5)}$$

$$\omega_x = \mathrm{Z}\frac{AWC_x}{P_x} \quad \text{(Eq.6)}$$

$$R_{xj} = \frac{K_{xj} \times ET_0}{P_x} \quad \text{(Eq.7)}$$

where: Y_x is the annual water yield of grid *x* (mm); AET_{xy} is the actual evapotranspiration of grid *x* (mm); P_x is the annual precipitation of grid *x* (mm); AET_{xj} /P_x is the Zhang coefficient; ω_x is the parameter indicating natural climate-soil properties; R_{xj} is the drying index of raster cell *x* on land type *j*; K_{xj} is the vegetation evapotranspiration coefficient of raster cell *x* on land type *j*; *Z f*actor is the seasonality factor (Fu, 1981; Zhang et al., 2004; Leh et al., 2013; Cong et al., 2020).

$$ET_0 = 0.0013 \times 0.408 \times RA \times (T_{avg} + 17) \times (TD - 0.0123P)^{0.76} \quad \text{(Eq.8)}$$

where: ET_0, RA, and P are potential evapotranspiration (mm/d), solar top atmospheric radiation ($MJ/(m^2\cdot d)$), and monthly average rainfall, respectively; T_{avg} is the mean value of daily maximum temperature mean and daily minimum temperature mean (°C); TD is the difference between daily maximum temperature mean and daily minimum temperature mean (°C).

The vegetation available water content (AWC) is obtained by subtracting the field water holding capacity (FMC) from the permanent wilting coefficient (WC) and is calculated as follows:

$$AWC_x = FMC_x - WC_x \quad \text{(Eq.9)}$$

$$FMC_x = 0.003075 \times Sand(\%) + 0.005886 \times Silt(\%) + 0.008039 \times Clay(\%) + 0.002208 \times OM(\%) - 0.1434 \times BD \quad \text{(Eq.10)}$$

$$WC_x = -0.000059 \times Sand(\%) + 0.001142 \times Silt(\%) + 0.005766 \times Clay(\%) + 0.002208 \times OM(\%) + 0.02671 \times BD \quad \text{(Eq.11)}$$

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where: Sand (%), Silt (%), Clay (%), OM (%) and BD and denote sand content (%), powder content (%), clay content (%), organic matter content (%), and soil bulk weight (g/cm^3), respectively.

(3) Carbon storage

The carbon storage module in the InVEST model mainly includes four basic carbon pools: aboveground carbon ($C_{\_above}$), belowground carbon ($C_{\_below}$), soil carbon ($C_{\_soil}$) and dead organic carbon ($C_{\_dead}$). The calculation equation of the model is as follows.

$$C_{\_tot} = C_{\_above} + C_{\_below} + C_{\_soil} + C_{\_dead} \quad \text{(Eq.12)}$$

where: $C_{\_tot}$, $C_{\_above}$, $C_{\_below}$, $C_{\_soil}$, and $C_{\_dead}$ denote the total carbon storage, carbon storage in the above-ground part, carbon storage in the below-ground part, soil carbon storage, and dead organic carbon storage. The carbon density values required for the measurement were mainly referred to literature sources and previous research results (Wang, 2000; Li, 2003; Lal, 2004; Fang, 2007; Chuai et al., 2013; Yang et al., 2018; Zhou et al., 2019) to determine the carbon pool table.

(4) Habitat quality

The habitat quality module calculates the habitat quality of each raster by setting the threat level of different land use types to external impact factors as well as the sensitivity, impact distance and weight of the threat factors (Leh et al., 2013; Song et al., 2020), which is calculated as follows.

$$Q_{xj} = H_j\left[1 - \left(\frac{D_{xj}^z}{D_{xj}^z + k^z}\right)\right] \quad \text{(Eq.13)}$$

where: Q_{xj} is the habitat quality of raster x in land type j; H_j is the habitat suitability of land type j; D_{xj} is the degree of habitat degradation of raster x in land type j; k is the half-saturation coefficient; z is the default normalization constant of the model. The habitat threat and sensitivity tables used in the module refer to previous research results, cases and data in the InVEST model user manual (Xie, 2004; Fan et al., 2018; Yang et al., 2018; Song et al., 2020; Liu et al., 2022), and are assigned with the actual situation in the study area.

Scenario setting

In this paper, the following three scenarios were set up to simulate and predict the land use types in the study area in 2030 under different scenarios, using the 2020 land use/cover as the base period data, and the specific scenarios are described as follows.

(1) Natural development scenario

Assuming that the land use types and spatial distribution in the study area from 2020 to 2030 are less influenced by natural environment, socio-economic and policy factors, and their land use changes still develop at the 2010-2020 rate, each land use

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type in the study area in 2030 is inferred. On this basis, it is assumed that other conditions such as meteorological elements, topography, soil, and socio-economic conditions remain unchanged, and only changes in land use types are considered to assess ecosystem service functions in the study area in 2030. Based on the number of land use changes in the study area from 2010 to 2020, the land use types in the study area in 2030 under the natural development scenario were simulated based on the CA-Markov model based on the land use conversion probability from 2010 to 2020 using IDRISI 17.0 software.

The CA-Markov model of IDRISI 17.0 software was used to simulate the 2010 land use data, and the accuracy of the simulated 2010 data was judged against the actual 2010 data, and the accuracy of both reached 96.29%, indicating that the simulation results of the model were more accurate.

(2) Urban and rural expansion scenario

With the establishment of Guangxi Beibu Gulf Economic Zone and China (Guangxi) Pilot Free Trade Zone, the promotion of the strategy of “city to city high-speed railway” and “county to county highway” in Guangxi, especially during “the 14th five-year plan for China’s national economic and social development” period in 2020, Guangxi will vigorously implement the strong capital strategy, build the Beibu Gulf city cluster and build a better and stronger Beibu Gulf Economic Zone, the social economy of the study area will be further developed. The implementation of the “two-child policy” by the central government in 2015 will promote the population growth of the study area. With reference to the development plan of the Beibu Gulf urban agglomeration, the draft outline of the 14th Five-Year Plan of Guangxi and the general land use plan of the six cities from 2006 to 2020, it is assumed that the economic and social development and population growth in the study area will lead to the expansion of urban and rural built-up land in the future.

Therefore, this paper uses 2020 land use data as the basis for buffer zone analysis and processing using ArcGIS platform, and all other land use types in the buffer zone are transformed into urban and rural built-up land, in which the buffer zone for general townships and rural settlements is set at 30 m, the buffer zone for towns above the central township level is set at 200 m, and the buffer zone for urban areas is set at 500 m, finally simulating the land use types of the study area in 2030 under the urban and rural expansion scenario.

(3) Ecological conservation scenario

It is assumed that ecological restoration measures, such as reforestation and grass restoration, will be taken in the study area, so that the vegetation in the study area will be restored to a certain extent and the ecological environment will be significantly improved. According to the relevant provisions of *China’s Soil and Water Conservation Law*, farmland on slopes over twenty-five degrees should not be reclaimed to grow crops. This paper sets up an ecological protection scenario in which all farmland in the study area with slopes greater than twenty-five degrees is returned to cultivation, in which all farmland on semi-shady and shady slopes is returned to forest, and all farmland on semi-positive and positive slopes is returned to grass. This scenario was also set considering the principle of operability, and the study was based on the 2020 land use data, and a series of operations such as slope orientation analysis, extraction,

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cropping and merging were performed on ArcGIS software to finally arrive at the 2030 land use data of the study area under the ecological conservation scenario.

Evaluation of trade-off and synergistic relationships

The spatial correlation analysis of ecosystem services in the study area was performed by using the spatial analysis tool of ArcGIS to calculate the correlation coefficients between the services in four periods: 2005, 2010, 2015, and 2020, which were then imported into SPSS software for testing. The formula for calculating spatial correlations among multiple variables was as follows.

$$R = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - x)^2}\sqrt{\sum_{i=1}^{n}(y_i - y)^2}} \quad \text{(Eq.14)}$$

where: *R* is the correlation coefficient; X_i, Y_i are the value of ecosystem service category *i* for *x* and *y*; $\bar{x}$ and $\bar{y}$ are the mean of *x* and *y*. when the correlation coefficient *R* between two ecosystem services was negative and passed the significance test of the 0.05 level, it was considered that there was a trade-off; otherwise, if the correlation coefficient *R* is positive and passes the test, the relationship is synergistic; if the correlation coefficient *R* is zero, there is no correlation. A larger absolute value of the correlation coefficient *R* indicates a stronger correlation, i.e., a greater degree of synergy or trade-off.

Identification of ecosystem multiple service important areas

Based on the actual situation of the study area and the assessment results of the InVEST model, this paper determines and delineates the core protection areas of ecosystem services in the study area, visualizes the spatial layout of the important areas of multiple ecosystem services in the study area, and thus grasps the supply capacity of various services in different spatial regions of the study area. The ArcGIS platform was used to overlay the raster layers of each service in the study area, and then the supply capacity of each service in each raster was calculated. Based on the number of occurrences of areas exceeding the average value of the respective ecosystem services, the study area was divided into five levels of multiple important ecosystem service areas (*Table 2*), and then the spatial distribution map of integrated important ecosystem service areas was obtained (*Fig. 4*).

Table 2. *Principles for the delineation of multi-service important areas of ecosystems*

Level	Classification principles
Extremely important area	Areas that can provide 4 ecosystem services above the average of an ecosystem service
Highly important area	Areas that can provide 3 ecosystem services above the average of an ecosystem service
Moderately important area	Areas that can provide 2 ecosystem services above the average of an ecosystem service
General important area	Areas that can provide 1 ecosystem service above the average of an ecosystem service
General area	Areas where all ecosystem services are below an average

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Results

Spatial and temporal characteristics of land use change

During 2005-2020, the land use pattern of the study area has changed significantly, with the largest fluctuations in the area of farmland and built-up land, both of which change in different directions, showing a continuous increase in the area of built-up land and a continuous decrease in the area of farmland, with the largest increase in the area of built-up land, with the increase accounting for 0.78% of the total area of the study area, and the largest decrease in the area of farmland, with the decrease accounting for 0.48% (*Table 3*). Farmland and forestland contributed the most to the increase in built-up land, while forestland was the largest source of the increase in the area of farmland, and the decrease in forestland was second only to farmland. The changes in the area of grassland, water body and unused land were not significant (*Table 4*).

Table 3. *Area and percentage of land use types during 2005-2020*

Year / Land use type	2005		2010		2015		2020		2005-2020	
	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)	Area (km²)	Percentage (%)	Area change amount (km²)	Area change rate (%)
Farmland	23664	24.77	23579	24.68	23369	24.46	22463	23.51	-1201	-5.08
Forestland	61373	64.24	61422	64.29	61242	64.10	61743	64.63	370	0.60
Grassland	6568	6.88	6511	6.81	6526	6.83	6489	6.79	-79	-1.20
Water body	1666	1.74	1681	1.76	1696	1.78	1696	1.78	30	1.80
Built-up land	2240	2.34	2318	2.43	2673	2.80	3118	3.26	878	39.20
Unused land	27	0.03	27	0.03	32	0.03	29	0.03	2	7.41
Total	95538	100	95538	100	95538	100	95538	100	—	—

Table 4. *Land use transfer matrix during 2005-2020*

2005 / 2020	Farmland	Forestland	Grassland	Water body	Built-up land	Unused land	Total
Farmland	21818.10	1091.67	53.38	73.98	626.41	0.36	23663.90
Forestland	401.50	60429.27	169.94	82.31	288.88	1.55	61373.45
Grassland	46.56	167.28	6246.14	24.13	83.24	0.12	6567.47
Water body	83.64	33.84	9.85	1499.87	35.73	2.75	1665.68
Built-up land	113.15	20.67	9.13	14.59	2082.47	0.05	2240.06
Unused land	0.28	0.38	0.48	0.82	0.95	24.49	27.40
Total	22463.23	61743.11	6488.92	1695.7	3117.68	29.32	95537.96

During the whole study period, with the rapid economic and social development and the rapid expansion of urban and rural areas, the new construction continuously occupies farmland without replenishing the amount of farmland, which makes the farmland in the study area continue to decrease and built-up land continue to increase, and the conversion of farmland into built-up land is most drastic in the river valley basin and the coastal zone of Beibu Gulf, which are areas with more developed socio-

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economic development and more frequent human activities. The distribution of forestland in nature reserves, forest parks and forestry management areas is the most intensive, and the spatial distribution does not vary much (*Fig. 2*). The study area is the karst-coastal zone in southwest Guangxi, and its land use pattern and intensity also show significant transitional characteristics. As a whole, the land use type in the study area transitions from predominantly forestland with high-density cover in the northwest to predominantly continuous flat farmland in the central and Beibu Gulf coastal areas, and from weak land use intensity in the northwestern karst area to stronger land use intensity in the Beibu Gulf area.

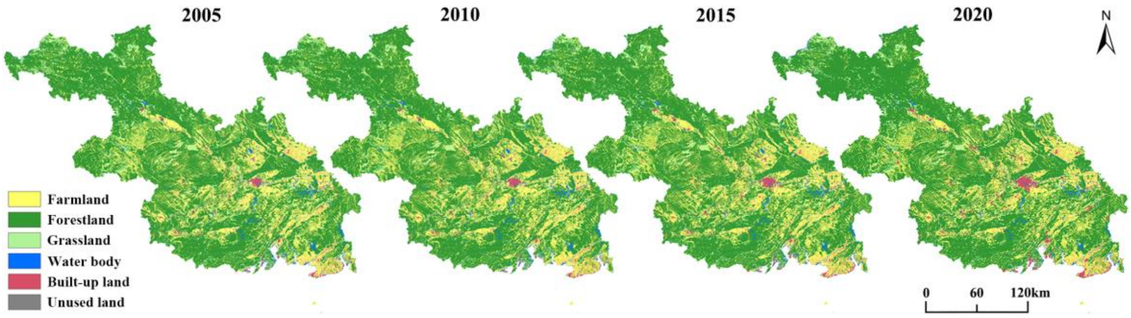

Figure 2. *Land use data in the four phases of 2005, 2010, 2015, 2020*

Spatial and temporal evolution of ecosystem services

The physical quality and spatial distribution patterns of the four ecosystem services of water yield, carbon storage, soil conservation and habitat quality in the study area were obtained by the InVEST model (*Fig. 3*).

The spatial distribution patterns of soil conservation, water yield, carbon storage, and habitat quality in the study area were generally consistent during 2005-2020, and the spatial heterogeneity was more obvious, with a general trend of gradual decrease from northwest to southeast. The overall trend of soil conservation is increasing, and the growth area gradually develops from northwest, west, southwest to central; the average water yield in the study area ranges from 366.37 to 904.66 mm, and the maximum value of water yield shows a trend of weak growth followed by a significant decrease, while the minimum value keeps decreasing; the overall trend of carbon storage shows a continuous decrease, and the decrease of carbon storage is small, but the carbon storage capacity of the ecosystems in the study area is still at a high level. The northwestern, southwestern and eastern parts of the study area were areas with high habitat quality, and the habitat quality index was around 0.8, and the habitat quality in the northwestern area gradually increased, while the habitat quality in the southwestern and eastern parts was more stable, and the spatial distribution pattern and area of areas with low habitat quality did not change much.

The high values of the four services of soil conservation, water yield, carbon storage and habitat quality mainly fall in the land type of forestland, and the high-coverage forestland mainly falls in nature reserves, forest parks and forestry management areas, which have high vegetation cover, rich species, low anthropogenic interference, low land use, and good and stable ecosystems. Therefore, nature reserves, forest parks, and forestry management areas are high value areas for soil conservation, water yield, carbon storage, and habitat quality, and forestland is one of the land types with the

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strongest function of the four ecosystem services. The low value areas of the four ecosystem services mainly occur in urban built-up land, farmland and other land use types. The concentrated urban built-up land and farmland are mainly located in the Left River-Right River-Yong River valleys and the coastal zone of Beibu Gulf where the terrain is flat, the economy and society are more developed and human activities are relatively frequent. Therefore, the Left River - Right River - Yong River valleys and the coastal zone of Beibu Gulf are low value areas for soil conservation, water yield, carbon storage and habitat quality.

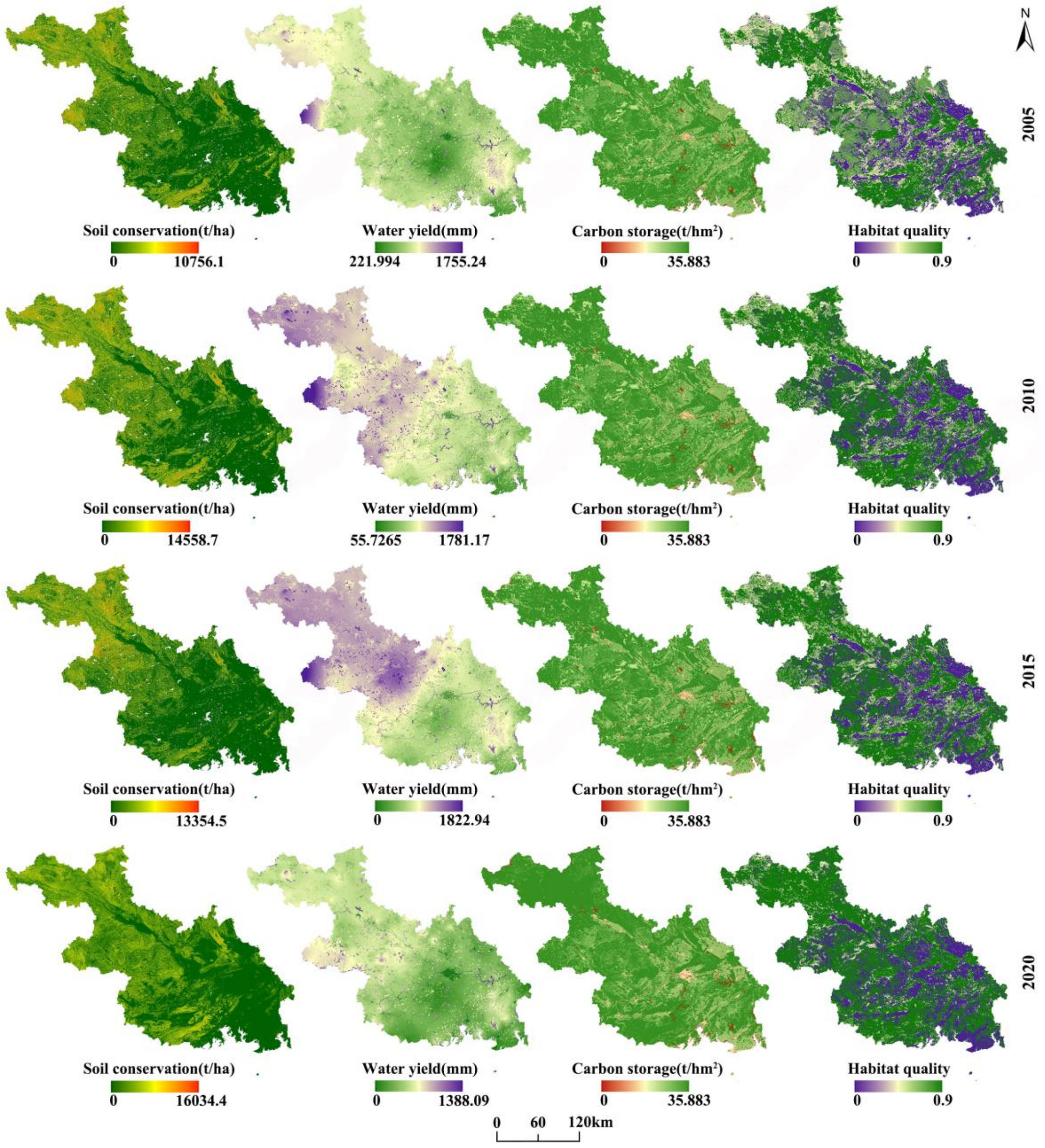

Figure 3. *Spatial distribution pattern of ecosystem services in the study area during 2005-2020*

As a whole, the supply capacity of four ecosystem services of soil conservation, water yield, carbon storage, and habitat quality, showed significant transitional

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characteristics, i.e., a transition from high ecosystem service supply capacity in the northwestern part of the study area to low ecosystem service supply capacity in the Beibu Gulf areas, with a general trend of tilting along the northwestern part of the study area toward the southeastern coast. The results show that changes in land use patterns in the study area lead to corresponding changes in ecosystem services, and that the supply capacity of each ecosystem service in this particular space shows consistent transitional characteristics with land use patterns and intensities.

Ecosystem service space trade-off

Ecosystem service space related analysis

As can be seen from *Table 5*, all four services in the study area showed positive spatial correlations among the four periods from 2005 to 2020, indicating that the ecosystem services are synergistic. The correlation coefficients between habitat quality and water yield were all high and positive, and showed a trend of decreasing and then increasing during the study period, while the correlation coefficients between soil conservation–water yield and water yield–carbon storage showed the opposite trend of the former, showing an increasing and then decreasing trend, and the correlation coefficients between habitat quality and carbon storage were the highest and fluctuated little. Habitat quality and carbon storage, habitat quality and soil conservation, showed strong positive correlations, and the correlation between water yield services and carbon storage was the weakest. The correlation between habitat quality and carbon storage from 2005 to 2020 was the highest (the correlation coefficients are 0.8006, 0.8002, 0.8053 and 0.8582, in that order), followed by the correlation between habitat quality and water yield (the correlation coefficients are 0.2961, 0.2948, 0.2162 and 0.3342, in that order), while the correlation between water yield and carbon storage were the lowest correlations.

Table 5. *Correlation coefficients between ecosystem services during 2005-2020*

	Correlation	Soil conservation	Water yield	Carbon storage	Habitat quality
2005	Soil conservation	1			
	Water yield	0.1958*	1		
	Carbon storage	0.2379*	0.0870*	1	
	Habitat quality	0.2403*	0.2961*	0.8006*	1
2010	Soil conservation	1			
	Water yield	0.2285*	1		
	Carbon storage	0.2384*	0.1216*	1	
	Habitat quality	0.2362*	0.2948*	0.8002*	1
2015	Soil conservation	1			
	Water yield	0.2791*	1		
	Carbon storage	0.1376*	0.2213*	1	
	Habitat quality	0.2526*	0.2162*	0.8053*	1
2020	Soil conservation	1			
	Water yield	0.1225*	1		
	Carbon storage	0.2406*	0.0838*	1	
	Habitat quality	0.2277*	0.3342*	0.8582*	1

*Correlation is significant at the 0.01 level

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Ecosystem service space related analysis

During 2005-2020, the ecosystem services in the study area were dominated by multiple service types, and the area above the important area was the largest, accounting for more than 70% of the total study area, and all ecosystem services showed a strong supply function, and the areas above the important area included two or more types of ecosystem services; While the general area was only one-third of the area of the important area, and the area had a single type of ecosystem service and weak services. Overlaying the spatial distribution map of the importance of integrated ecosystem services in the study area with the current land use map, it was found that the areas with higher importance of integrated ecosystem services mostly occurred in the land type of forestland, which was obviously concentrated in the nature reserves, forest parks and forestry management areas of Cenwang Old Hill, Admiralty Hill, Hundred Thousand Mountains and Daming Mountain; The general area mostly occurs in the two land types of built-up land and farmland, and all ecosystem services were weak or mostly single type of ecosystem services (*Fig. 4*).

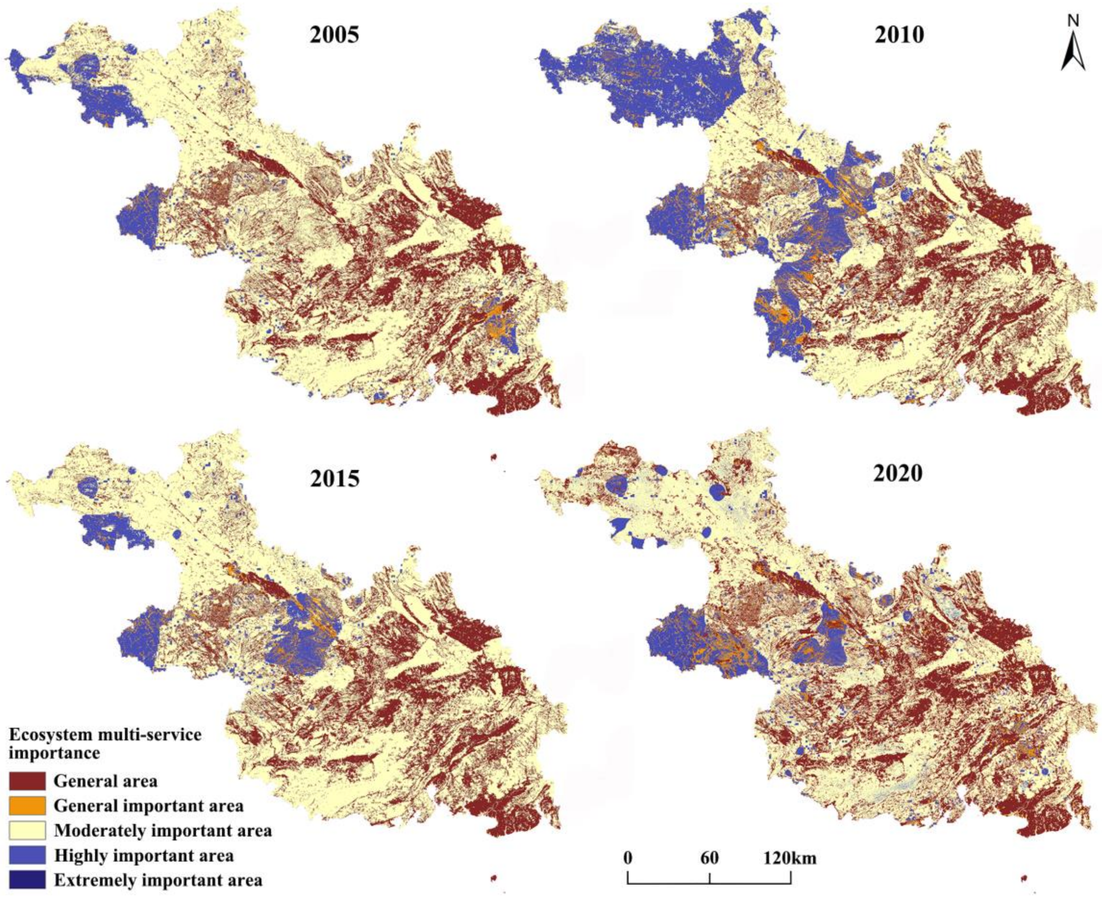

Figure 4. *Distribution of the importance of multiple ecosystem services in the study area during 2005-2020*

Ecosystem service time trade-off

Based on the three different land use scenarios of natural development, urban-rural expansion and ecological conservation, each ecosystem service in the study area in 2025 was simulated based on the InVEST model to assess time trade-off of each ecosystem service in the study area, and the results are shown in *Figure 5*.

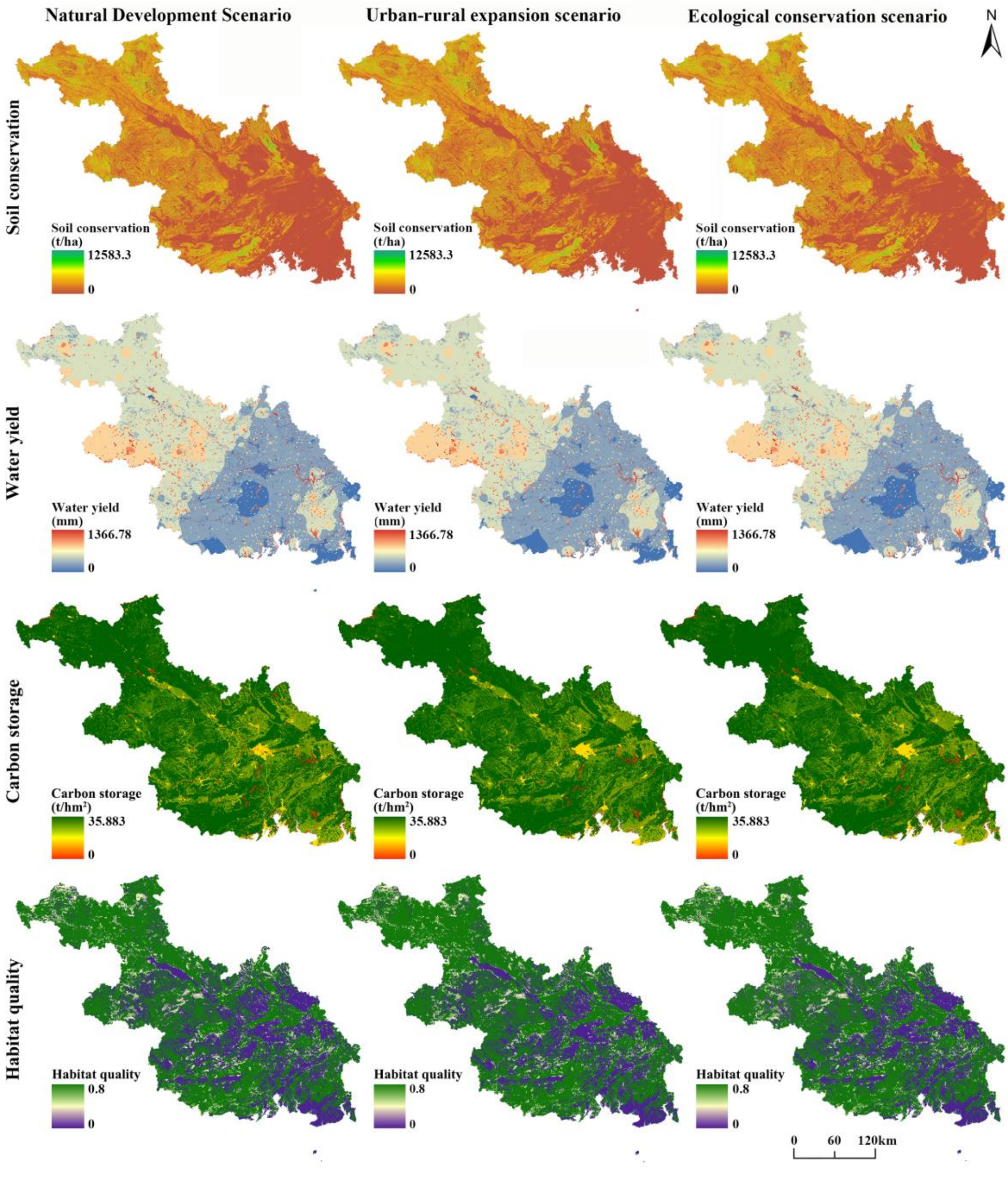

Figure 5. *Spatial distribution patterns of various ecosystem services in the study area under different scenarios*

Under the natural development scenario, the ecosystem services in the study area did not change much. Spatially, the high value areas of ecosystem services are still concentrated in nature reserves, forest parks and forestry management areas where human activities are less disturbed, while the low value areas are concentrated in the Left River-Right River-Yong River valleys and the coastal zone of Beibu Gulf, where human activities are frequent and farmland is concentrated in a continuous manner. The

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supply capacity of soil conservation, carbon storage, water yield, and habitat quality was reduced. Compared to 2020, the mean and maximum values of water yield in the study area decreased from 366.37 mm and 1388.09 mm to 361.28 mm and 1366.78 mm, respectively. The carbon storage was 29.465×10^8 t, which was 1.275×10^8 t less than that in 2020. These phenomena suggest that the supply capacity of soil conservation, carbon storage, water yield and habitat quality are all diminished under the development of natural development scenarios, and the four services show synergistic relationships with each other.

Under the urban-rural expansion scenario, soil retention, charcoal storage, water yield, and habitat quality in the study area are weakened. Among them, the mean and maximum values of water yield in the study area decreased from 366.37 mm and 1388.09 mm to 363.64 mm and 1366.78 mm, respectively, compared to 2020. The carbon storage was 30.582×10^8 t, which showed a decreasing trend. The spatial distribution patterns of high and low value areas of ecosystem services under this scenario and the natural development scenario are generally consistent. It can be seen that the supply capacity of soil conservation, carbon storage, water yield, and habitat quality are weakened under the urban-rural expansion scenario, and the four services show a synergistic relationship with each other.

Under the ecological conservation scenario, the four ecosystem services of soil conservation, carbon storage, water yield, and habitat quality increased slightly in the study area, and the spatial distribution patterns of high and low value areas of ecosystem services were roughly the same as those under the natural development scenario. Among them, the growth of carbon storage and habitat quality is relatively obvious, with the total value of carbon storage being 30.786×10^8 t, and its total value has decreased by 0.046×10^8 t compared to 2020. Thus, the supply capacity of soil conservation, carbon storage, water yield and habitat quality are all enhanced under the ecological conservation scenario, and the four ecosystem services show synergistic relationships with each other.

In summary, the natural development scenario and the urban-rural expansion scenario show a significant decrease in all ecosystem services. Under the ecological conservation scenario, the ecosystem services increased significantly. Considering the current national strategic development and the current land use situation in the study area, the ecological conservation scenario will be more in line with the development needs of the study area if high quality and sustainable provision of ecosystem services and sustainable development of the region is set as the goal.

Conclusion and discussion

This study analyzed the land use change characteristics of the karst-coastal zone in southwest Guangxi from 2005 to 2020, and also used the InVEST model and scenario simulation method to assess the supply capacity of habitat quality, soil conservation, water yield and carbon storage in the study area, and explored the spatial and temporal trade-off or synergistic relationships of each ecosystem service, and mainly obtained the following conclusions.

(1) The land use pattern in the study area changed significantly between 2005 and 2020, with the most pronounced changes in built-up land, farmland and forestland. Among them, farmland continued to decrease and built-up land continued to increase, and the conversion of farmland into built-up land was most dramatic in the distribution

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of the river valley and the coastal zone of Beibu Gulf. Farmland and forestland contribute the most to the increase in built-up land, while forestland is the largest source of increase in the area of farmland, and the area of grassland, water body and unused land does not change much. During the 15 years, although the area of forestland decreased, it still had the largest area share and was widely distributed in all regions of the study area, with nature reserves, forest parks and forestry management areas being the most concentrated. As a whole, its land use pattern and intensity show significant transitional characteristics.

(2) The characteristics of changes in the four services of soil conservation, carbon storage, water yield and habitat quality in the study area between 2005 and 2020 had similar regularity, and the spatial distribution pattern did not change much, and the high value areas of ecosystem services were mainly concentrated in nature reserves, forest parks and forestry management areas, and the supply capacity of soil conservation, carbon storage, water yield and habitat quality in forestland were the largest. The low-value areas are mostly concentrated in the Left River-Right River-Yong River valleys and the coastal zone of Beibu Gulf. On the whole, the supply capacity of all services in the study area shows significant transitional characteristics, and is consistent with the transitional characteristics of land use patterns and intensities.

(3) The study area showed positive spatial correlations among the ecosystem services, and there were synergistic relationships, i.e., each ecosystem service had the same trend of change. The ecosystems in the study area are dominated by multiple service types, and the high importance areas of integrated ecosystem services mostly occur in forestland types, mainly in nature reserves, forest parks and forestry management areas where human activities have less influence; the general areas are mostly built-up land, farmland and other land types, and the various ecosystem services are weak or biased towards a certain type of ecosystem service.

(4) The supply capacities of soil conservation, carbon storage, water yield services and habitat quality are reduced under the natural development scenario and the urban-rural expansion scenario; the supply capacities of soil conservation, carbon storage, water yield and habitat quality are increased under the ecological protection scenario. The ecological conservation scenario is more suitable for the development needs of the study area if high-quality provisioning of all ecosystem services and sustainable development of the region are the main development objectives. Under different land use scenarios, there are still significant transitional characteristics in the spatial supply capacity of services in the study area.

This paper analyzes the ecosystem service functions of the southwest-Karst-coastal zone of Guangxi using the InVEST model, which is expected to provide a reference basis for relevant decision makers to better grasp the actual situation of ecosystem services in the region, implement more scientific and effective management, ensure ecological security and maintain sustainable development. However, ecosystems supply a variety of services. In addition to the four services mentioned in this study, namely soil conservation, habitat quality, water production services and carbon storage, other services such as water purification, climate regulation, aesthetics and ecotourism are equally important. In future studies, it is still necessary to pay attention to the assessment of services such as water purification and climate regulation in order to have a more comprehensive understanding of the magnitude and changing characteristics of regional ecosystem service supply capacity.

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