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Spatiotemporal evolution and influencing factors of ecosystem service value in the Sanjiangyuan nature reserve

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Abstract. Evaluating the temporal and spatial changes in the ecosystem service value (ESV) of the Sanjiangyuan Nature Reserve is important for understanding the impact of human activities on natural ecosystem and guiding ecosystem restoration and environmental pollution control. In this study, remotely sensed land-cover data and the equivalent factor method were used to analyze the spatiotemporal evolution characteristics of the ESV in Sanjiangyuan Nature Reserve from 1992 to 2015, and regression analysis was employed to determine the factors driving changes in the ESV. The results show that grassland was the main type of ecosystem in the study area, and the transformation of grassland into bare areas was the primary change in land cover. Additionally, the ESV in the study area first decreased and then increased, with an annual growth rate of 0.69%. The ESV mainly increased in the north of the Yellow River's source area, and mainly decreased in the northwest of the Yangtze River's source area. Finally, the gross output value of agriculture, urbanization rate and proportion of secondary industry were found to be the main factors driving the ESV in the study area.

Keywords: driving force; ecosystem service value; environmental pollution; hotspot analysis; Sanjiangyuan nature reserve

1. Introduction

Ecosystem service value (ESV) refers to the products and services that humans directly or indirectly obtain through the structure, process, and function of natural ecosystems (Daily 2013, Toghroli *et al*. 2014, Safa *et al*. 2016, Sedghi *et al*. 2018, Katebi *et al*. 2019, Shariati *et al*. 2020d). Researching the ESV is conducive to understanding the basic characteristics of natural ecosystems, and is vital for formulating reasonable regional development strategies and ecological protection policies, and achieving sustainable regional development. Since the 1990s, researchers in China and overseas have conducted much research on ESV evaluation, and the existing ESV evaluation methods can be divided into two categories, i.e., those based on the unit service function price (functional price method) (Costanza *et al*. 1997, Bolund and Hunhammar 1999, Zhao *et al*. 2003, Daily 2013, Wang *et al*. 2014b, NDRC 2018), and those based on the equivalent factor of the unit area value (equivalent factor method). The equivalent factor method is more simple to use with lower data demand and higher result comparability than the functional value method, and can facilitate comprehensive evaluation and be used to evaluate the ESV on a large spatial scale. This method provides a conceptual basis and theoretical support for researchers to analyze the ecosystem service function and value of a region, and supports ESV evaluation research. To date, the equivalent factor method has been widely used in the evaluation of the ESV of wetlands, forests, grasslands, and lakes (Fazaeli *et al*. 2016, Ghazanfari *et al*. 2016, Habibi *et al*. 2018a, b, Hosseini *et al*. 2018, Alipour *et al*. 2020, Cheshmeh *et al*. 2020, Ghabussi *et al*. 2020, Ghazanfari *et al*. 2020, Li *et al*. 2020a, b, Liu *et al*. 2020a, b, Moayedi *et al*. 2020c, Shariati *et al*. 2020c, Shi *et al*. 2020, Wang *et al*. 2020b).

Sanjiangyuan Nature Reserve is the headwater catchment area of the Yangtze and Yellow Rivers, and the Lancangjiang, thus, it is an important supply area of freshwater resources in China and Southeast Asia. Under the combined effects of natural factors and severe human activities, grassland degradation, lake shrinkage, soil pollution, soil erosion, water pollution, biodiversity reduction, and other ecological problems have manifested in Sanjiangyuan Nature Reserve in recent decades, and the area is facing a severe ecological crisis. This crisis has attracted widespread attention in China and other countries (Mansouri *et al*. 2016, Shariati *et al*. 2019b, d, Trung *et al*. 2019b, Yazdani *et al*. 2020). A series of ecological protection and restoration projects implemented since 2000 has curbed the degradation trend of the Sanjiangyuan Nature Reserve ecosystem, and the ecological environment has improved significantly. Studying the evolution characteristics of the ESV in Sanjiangyuan Nature Reserve and analyzing its influencing factors will aid in understanding the driving effect of human activities on the natural ecosystem, which is vital for the ecological protection and management of Sanjiangyuan Nature Reserve. Although Zheng *et al*. (2020) have researched this topic, few studies have been conducted on the overall ESV of Sanjiangyuan Nature Reserve, and the existing studies are insufficient. The direct use of equivalent factors often results in great differences between the evaluation results and actual value,

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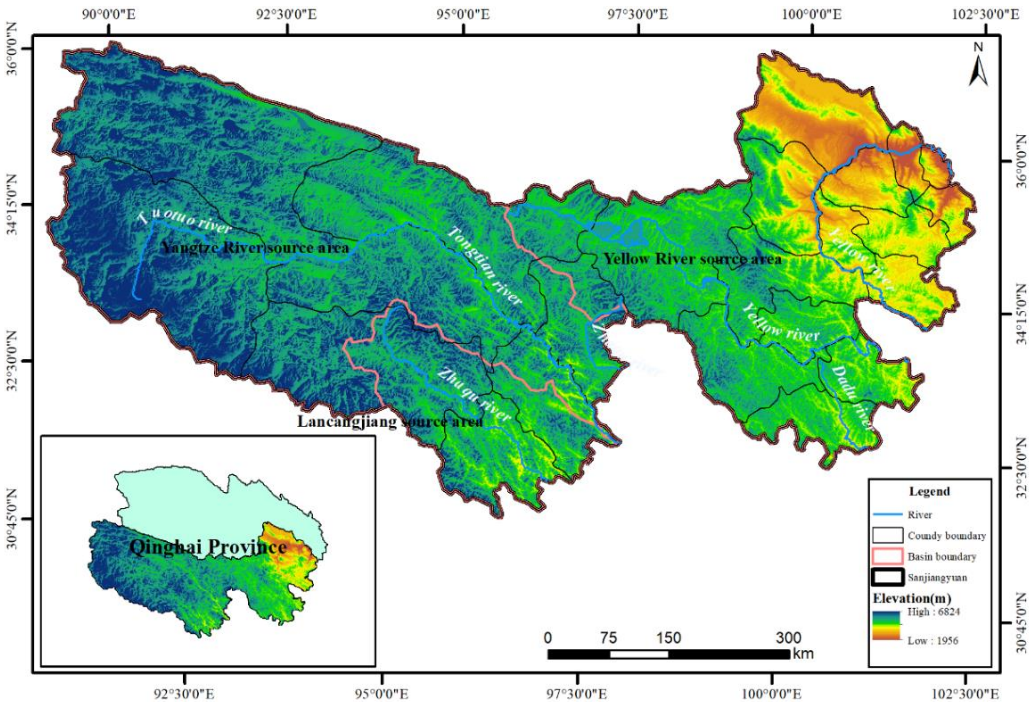

Fig.1 Location of Sanjiangyuan nature reserve

therefore, the table of equivalent factors should be corrected according to the actual situation of the study area during practical application. Additionally, it is difficult to accurately reflect the spatiotemporal variation characteristics of ESV in the study area using data from a few time periods, resulting in a lack of systematic discussion regarding the factors driving ESV changes in Sanjiangyuan Nature Reserve (Kim *et al*. 2014, Hamidi *et al*. 2015, Allahkarami *et al*. 2017, Ehyaei *et al*. 2017a, Akbas 2018a, b, Arefi and Zenkour 2018, Aydogdu *et al*. 2018, Bensaid *et al*. 2018, Fonge *et al*. 2019, Navi *et al*. 2019, Ebrahimi *et al*. 2020b, Gafour *et al*. 2020, Matouk *et al*. 2020, Shen *et al*. 2020, Chacko *et al*. 2021, Chen *et al*. 2021, Fang *et al*. 2021, Li *et al*. 2021, Pan and Chen 2021, Xu *et al*. 2021a, Yin *et al*. 2021, Liu *et al*. 2022, Wu *et al*. 2021).

To fully understand the ESV of Sanjiangyuan Nature Reserve and its change characteristics, land-use data obtained from 1992 to 2015 with a spatial resolution of 300 m were used to calculate the ESV of different ecosystems and their services in the nature reserve during different periods. The value equivalent factors of the main ecosystems were also corrected based on the value equivalent factor table of terrestrial ecosystems in China proposed by Xie *et al*. (2003). Based on this, the change characteristics and differences in the spatial distribution of the ESV were analyzed (Costanza *et al*. 1997, Bolund and Hunhammar 1999, Zhao *et al*. 2003, Shariati *et al*. 2011b, 2019a, Sinaei *et al*. 2011, Daily 2013, Wang *et al*. 2014b, Shahabi *et al*. 2016, Khorramian *et al*. 2017, NDRC 2018). To elucidate the mechanism by which human activities influence the ESV and provide a reference for ecosystem protection planning and scientific management in Sanjiangyuan Nature Reserve, a multiple regression model was used to analyze the impact of human activities on changes in the ESV (Moayedi *et al*. 2020a, b, Oyarhossein *et al*. 2020, Shariati *et al*. 2020b, Zhou *et al*. 2020, Dai *et al*. 2021b, Guo *et al*. 2021a, b, He *et al*. 2021, Huang *et al*. 2021a, Huo *et al*. 2021, Liu *et al*. 2021b, Peng *et al*. 2021, Shao *et al*. 2021, Zhang *et al*. 2021a, b, c).

2. Materials and methods

2.1 Study area

Sanjiangyuan Nature Reserve (89°50′57″~99°14′57″E, 32°22′36″~36°47′53″N) is the origin of the Yangtze and Yellow Rivers, and Lancangjiang in China, and is known as the “water tower of Asia”. The reserve is located in western China, the hinterland of the Qinghai Tibetan Plateau, and southern Qinghai Province, bordering Sichuan Province to the east and southeast, and the Tibet Autonomous Region to the south and west, and is the largest nature reserve with the highest altitude in China. The source areas of the Yangtze and Yellow Rivers, and Lancangjiang are 184800, 145100, and 39500 km^2, accounting for 50.03%, 39.60%, and 10.37% of the region, respectively. The annual average temperature is -5.6 - 7.8℃, and the average precipitation is 262.2-772.8 mm. The main soil type is alpine meadow soil, with frozen soil covering a large area. Sanjiangyuan Nature Reserve is located in the transition area between alpine meadow and desert in the Qinghai Tibetan Plateau. The main vegetation types are alpine grassland, meadow, and slope vegetation (Dai *et al*. 2021a, Ebrahimi *et al*. 2021, Hashemi *et al*. 2021, Hou *et al*. 2021b, Huang *et al*. 2021b, e, Jiao *et al*. 2021, Liu *et al*. 2021a, c, Ma *et al*. 2021, Moradi *et al*. 2021, Najaafi *et al*. 2021, Shariati *et al*. 2021, Wu and Habibi 2021b, Xu *et al*. 2021b, Zhao *et al*. 2021, Yu *et al*. 2022).

2.2 Data source and methodology

2.2.1 Data source

Land-use, administrative boundary vector, and socio-economic statistical data were mainly used to evaluate the ESV of Sanjiangyuan National Nature Reserve. The land-use and administrative boundary data were obtained from National Tibetan Plateau Data Center. The land-use dataset includes integrated NOAA, AVHRR, SPOT, ENVISAT, PROBA-V, and other vegetation classification product data combined with China's 1:100000 vegetation classification data for quality correction from 24 periods, and has a spatial resolution of 300 m. The land-use data for Sanjiangyuan Natural Reserve were reclassified into the following six categories according to the current land-use classification (GB/T 21010-2017): cropland, forest, grassland, waters, wetland, and bare areas. The socio-economic statistical data were obtained from Qinghai Statistical Yearbook (1993-2016) and the National Bureau of Statistics (Habibi *et al*. 2016a, 2018b, c, 2019b, d, e, Ebrahimi *et al*. 2019, Esmailpoor Hajilak *et al*. 2019, Ghabussi *et al*. 2019, Pourjabari *et al*. 2019, Safarpour *et al*. 2019a, 2020b, Moayedi *et al*. 2020b, Shariati *et al*. 2020a, Shokrgozar *et al*. 2020).

2.2.2 Land-use transition matrix

A land-use transition matrix was developed to study the land-use transformation direction and characteristics, which can not only reveal the land-use structure at a certain time, but also quantitatively describe the dynamic process of the mutual transformation of various land-use types during a certain period, allowing the change direction of various land-use types to be described (Ma *et al*. 2021, Zhao *et al*. 2021, Liu and Zhu 2010, Hou *et al*. 2021a, Huang *et al*. 2021b, c, Jiao *et al*. 2021, Liu *et al*. 2021c, Moradi *et al*. 2021, Xu *et al*. 2021b, Yu *et al*. 2022). The calculation formula is as follows (Shariati *et al*. 2011a, 2019c, Ziaei-Nia *et al*. 2018, Trung *et al*. 2019a, Afshar *et al*. 2020):

$$S_{ij} = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} i,j = 1,2,3,\dots,n \qquad (1)$$

where S is the area, S_{ij} is the area of land type i transformed into land type j, n is the number of land use types, and i and j represent the land use types before and after transformation, respectively (Azimi *et al*. 2016, Ebrahimi and Shafiei 2016, Ghadiri and Shafiei 2016a, b, c, Ghadiri *et al*. 2016a, b, c, d, Shafiei *et al*. 2016a, b, c, d, e, f, g).

2.2.3 ESV estimation

The equivalent factor method proposed by Xie *et al*. (2003) was followed to calculate the ESV of the Sanjiangyuan Nature Reserve. According to the relevant literature, one standard equivalent factor of the terrestrial ecosystem in China was 3406.5 yuan/hm^2 in 2010 (ZHANG *et al*. 2017).

Using the value equivalent table of the terrestrial ecosystem in China to calculate the regional ESV directly typically causes the result to deviate from the actual value, thus, it must be corrected. The ESV coefficient of cropland was corrected based on the grain yield per unit area, and while those of forest and grassland were corrected based on net primary productivity data. The corrected cropland, forest, and grassland coefficients were 13.1, 0.09, and 0.22, respectively. As the other land-use types covered relatively small areas and the coefficient correction model was complex, their coefficients were not corrected in this study. The corrected equivalent ESV per unit area in the study area is presented in Table 1.

The ESV of Sanjiangyuan Nature Reserve was evaluated based on the area of different land-use types from 1992 to 2015 and the corrected equivalent table of ESV per unit area with the following calculation formula (Wang *et al*. 2014b, 2020a, Habibi *et al*. 2017, Safarpour *et al*. 2018, Habibi *et al*. 2019a, c, Safarpour *et al*. 2019b, 2020a, Al-Furjan *et al*. 2020c, Alipour *et al*. 2020, Ebrahimi *et al*. 2020a, Ghabussi *et al*. 2020, Ghazanfari *et al*. 2020, Jermsittiparsert *et al*. 2020):

$$ESV = \sum_{k=1}^{n} (VC_k \times A_k) \qquad (2)$$

$$ESV_f = \sum_{k=1}^{n} \left(VC_{fk} \times A_k\right) \qquad (3)$$

where ESV is the total value of ecosystem services in the study area (yuan), VC_K is the ESV per unit area coefficient of land-use type k (yuan/hm^2), A_k is the area of land-use type k (hm^2), ESV_f is the ESV of ecosystem service function f (yuan), VC_{fk} is the value coefficient for land use type k with ecosystem service function f (yuan/hm^2), and n is the number of land use types.

2.2.4 Analysis of the ESV change trend

In this study, the slope analysis method was followed to simulate the change trend of ESV in Sanjiangyuan Natural Serve on a pixel scale. The calculation formula is as follows (Stow *et al*. 2003, Guo *et al*. 2017):

$$slope = \frac{n \times \sum_{i=1}^{n} i \times A_i - \sum_{i=1}^{n} i \sum_{i=1}^{n} A_i}{n \times \sum_{i=1}^{n} i^2 - \left(\sum_{i=1}^{n} i\right)^2} \qquad (4)$$

where $slope$ is the change trend of ESV during the study period, n is the number of years, which was 24 in this study, and A_i is ESV of year i. A $slope$ value of > 0 indicates that the ESV was increasing during the study period, otherwise, it was decreasing.

2.2.5 Hotspot analysis

Hotspot analysis is a spatial analysis and mapping technique that can be used to identify the clustering of spatial phenomena. Relevant studies show that the G_i statistical method is superior to and more scientific than other hotspot mapping methods as it can classify statistical significances and the connectivity of cold and hot spots. This tool can be used to identify statistically significant spatial clusters of high (hot spots) and low (cold spots) ESVs. The z-value of each pixel can be calculated using the Getis-Ord Gi* tool in ArcGIS software. The higher (or lower) the z-score, the more intense the clustering. A z-score close to zero indicates no apparent spatial clustering. The calculation formula is as follows (Wang *et al*. 2019, Fu *et al*. 2020):

Table 1 Ecosystem service value unit area coefficient of terrestrial ecosystems in Sanjiangyuan Nature Reserve, Unit: Yuan/hm^2

Types of ecosystem	Regulating services			Supporting services			Provisioning services		Cultural services
	Gas regulation	Climate regulation	Water supply	Soil conservation	Waste disposal	Biological diversity	Food production	Raw material production	Aesthetic
Cropland	1238.26	2204.11	1485.92	3615.73	4061.50	1758.33	2476.53	247.65	24.77
Forest	2861.46	2207.41	2616.19	3188.48	1071.00	2665.25	81.76	2125.66	1046.48
Grassland	1417.10	1594.24	1417.10	3454.19	2320.51	1930.80	531.41	88.57	70.86
Wetland	6131.70	58251.15	52800.75	5825.12	61930.17	8516.25	1021.95	238.46	18906.08
Bare areas	0.00	0.00	102.20	68.13	34.07	1158.21	34.07	0.00	34.07
Water	0.00	1566.99	69424.47	34.07	61930.17	8482.19	340.65	34.07	14784.21

$$G_i = \frac{\sum_{j=1}^{n} w_{i,j} x_j - X \sum_{j=1}^{n} w_{i,j}}{S \sqrt{\frac{\left[n \sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}} \quad (5)$$

where G_i is the output statistical z-score, x_j is the attribute value of element j, w_{ij} is the spatial weight between elements i and j, x and S are the mean value and standard deviation of the corresponding element, respectively, and n is the number of elements (Ebrahimi and Shafiei 2017, Ebrahimi *et al*. 2017, Ehyaei *et al*. 2017b, Ghadiri *et al*. 2017a, b, c, d, e, Mirjavadi *et al*. 2017a, b, c, d, Shafiei and Kazemi 2017a, b, Shafiei *et al*. 2017a, b, c, d, 2019, 2020, Shivanian *et al*. 2017, Azimi *et al*. 2018, Shafiei and She 2018).

2.2.6 Influencing factors analysis

Multiple linear models describe a continuous response variable as a function of one or more predictor variables, and were used to describe the relationship between the ESV and driving factors in this study. The model is expressed as follows (Adamian *et al*. 2020, Al-Furjan *et al*. 2020a, b, Li *et al*. 2020b, Liu *et al*. 2020a, b, Shi *et al*. 2020, Wang *et al*. 2020b, Zare *et al*. 2020, Zhou *et al*. 2020, Dai *et al*. 2021a, c, Guo *et al*. 2021a, Habibi *et al*. 2021, He *et al*. 2021, Huang *et al*. 2021a, Huo *et al*. 2021, Liu *et al*. 2021b, Peng *et al*. 2021, Shao *et al*. 2021, Wu and Habibi 2021a, Zhang *et al*. 2021a, c):

$$y_i = \beta_0 + \sum_i \beta_i x_i \quad (6)$$

where y_i is the total value of various ecosystem services, β_0 is the constant, β_i is the coefficient between driving factors i and y_i, and x_i is the value of driving factor i.

3. Results

3.1 Land use change analysis

The area of different land-use types in Sanjiangyuan Nature Reserve decreased in the order of grassland ≫ water > cropland > bare areas > forest > wetland. Grassland was the main ecosystem type in Sanjiangyuan Nature Reserve, covering an area of 335899.12 km^2 in 2015, accounting for 90.94% of the total area. Water was the secondary ecosystem, covering an area of 11520.71 km^2 and accounting for approximately 3.15% of the region. The main areas with this type of land use were the lakes of Gyaring and Ngoring in the mainstream of the Yellow River, and the many plateau lakes in the source of the Yangtze River in the west. Bare areas and cropland covered areas of 10411.08 and 9776.19 km^2, accounting for 2.82% and 2.65% of the Sanjiangyuan Nature Reserve, respectively. Cropland was mainly distributed along rivers and lakes. Forest and wetland covered the smallest areas, accounting for only 0.35% and 0.09% of the total area, respectively. Forest was mainly distributed in the mountainous area of the Yellow River's source region in the east of Sanjiangyuan Nature Reserve.

The areas of cropland and water increased the most during 2015, expanding by 342.15 and 260.60 km^2 at rates of 3.63% and 2.29%, respectively. The areas of forest and wetland increased slightly by 12.16 and 5.48 km^2 at rates of 0.94% and 1.61%, respectively. In contrast, the areas of grassland and bare areas in Sanjiangyuan Nature Reserve decreased, with the area of grassland decreasing by 290.41 km^2 from that in 1992 at a rate of less than 1%.

From 1992 to 2015, approximately 1.02% of the land-use types in Sanjiangyuan Nature Reserve changed, accounting for a total area of 3783.46 km^2. The transformation direction of land-use type during the study period was mainly between grassland and bare areas. Grassland accounted for the largest area of transformed land, with a total area of 1930.52 km^2 (approximately 0.57% of the total grassland area), 519.58, 904.85, and 502.03 km^2 of which was converted into cropland, bare areas, and water, respectively. Bare areas accounted for the largest area of transformed land, with a total area of 1331.19 km^2 (approximately 12.39% of the total area of bare areas). Most of these areas were converted into grassland. Most land was transformed into grassland, with a total transfer area of approximately 1640.11 km^2 (approximately 0.49% of the total grassland area), most of which were initially bare areas. Proportionally, most land was transformed into bare areas, with a total transfer area of 1001.21 km^2, accounting for approximately 9.62% of the total area of bare areas, which mainly originated from grassland.

The areas undergoing land-use change were mainly concentrated in the northeast and northwest of Sanjiangyuan Nature Reserve. Grassland mainly expanded in the south and center of Gonghe and Guinan Counties in the northeast of the Yellow River source areas, while bare areas mainly expanded in the west of Qumarleb County and the northern border area with Zhiduo County in the Yangtze River source

Table 2 Land-use transition matrix from 1992 to 2015, Unit:km^2

		1992						% of area	Total area
		Cropland	Forest	Grassland	Wetland	Bare areas	Water		
2015	Cropland	9251.88	0	519.58	0	1.72	3.01	2.65	9776.19
	Forest	0	1286.57	4.07	0	0	9.14	0.35	1299.78
	Grassland	172.22	0	334259.01	0	1237.66	230.22	90.94	335899.12
	Wetland	0	0	0	338.49	0	7.05	0.09	345.54
	Bare areas	8.73	0	904.85	0.08	9409.87	87.55	2.82	10411.08
	Water	1.21	1.05	502.03	1.49	91.80	11023.13	3.15	11620.71
% of area			2.55	0.35	91.02	0.09	2.91	3.08	1
Total area			9434.04	1287.62	336189.54	340.06	10741.06	11360.10	-

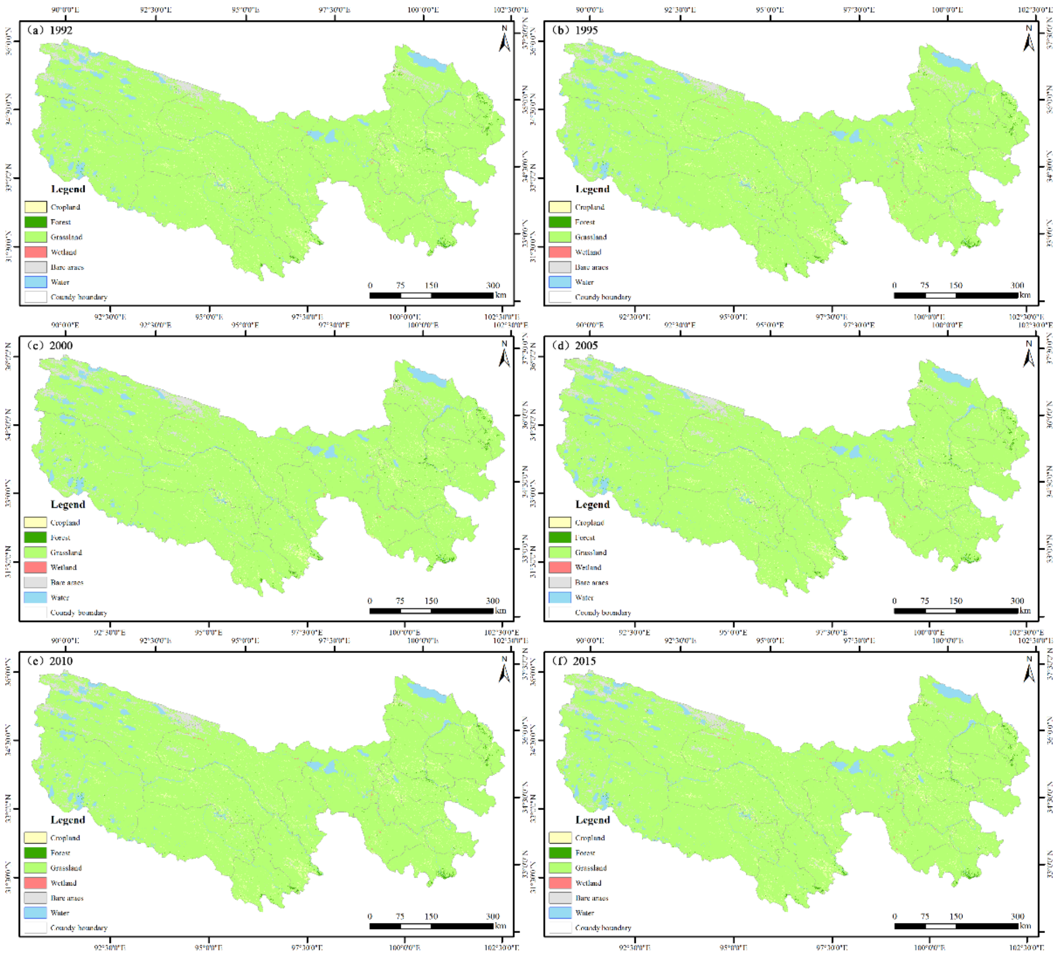

Fig. 2 Land-use patterns of Sanjiangyuan Nature Reserve in 1992, 1995, 2000, 2005, 2010, and 2015

area. The expanded water areas exhibited clear spatial agglomeration and were mainly distributed along the Yellow River in the east and near lakes in the west of the study area.

3.2 Spatiotemporal ESV characteristics

3.2.1 Temporal characteristics

ESV components

The ESV of Sanjiangyuan Nature Reserve was calculated based on the corrected ESV per unit area equivalent table and land-use data. From 1992 to 2015, the annual average ESV in Sanjiangyuan Natural Reserve was 640.683 billion yuan/year. The main type of ESV was supporting service value, accounting for 55.40% of the total value of the study area, followed by regulating service value, accounting for 37.64%. The provisioning and cultural service values were relatively small, accounting for only 3.79% and 3.18% of the total value, respectively. Grassland was the main ecosystem type with the highest ESV, accounting for 67.37% of the ESV of the study area. The ESV of water was also relatively high, accounting for28.30%, while that of cropland was relatively low, accounting for 2.58%. The ESVs of wetland, forest, and

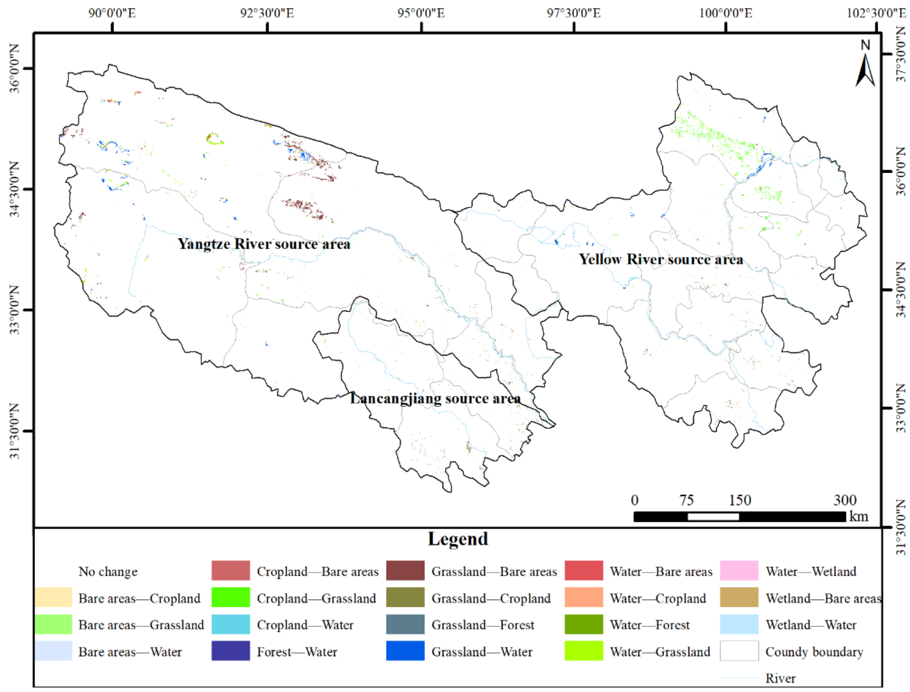

Fig. 3 Land-use transition map of Sanjiangyuan Nature Reserve from 1992 to 2015

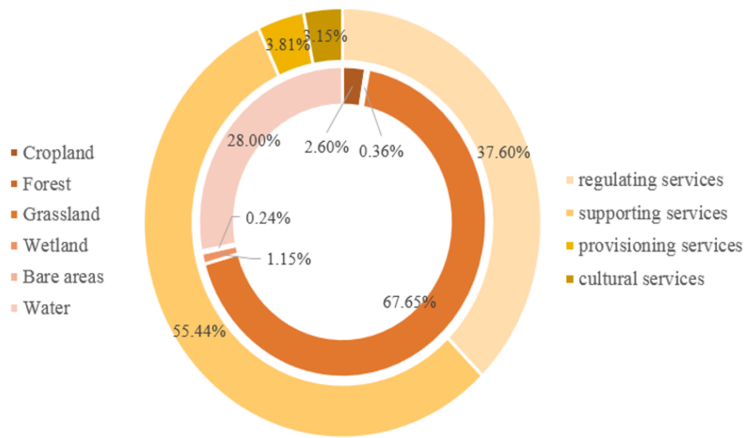

Fig. 4 ESV components in Sanjiangyuan nature reserve

Table 3 Variation in the ESV of Sanjiangyuan nature reserve from 1992 - 2015

Ecosystem service functions		Value/100 million yuan						Change percentage/%
		1992	1995	2000	2005	2010	2015	
Regulating services	Gas regulation	493.87	493.81	493.63	493.66	493.67	493.95	0.02
	Climate regulation	597.21	597.14	596.99	597.42	597.70	598.26	0.18
	Water supply	1301.52	1301.03	1288.99	1300.80	1311.99	1320.00	1.42
Supporting services	Soil conservation	1202.58	1202.43	1202.12	1202.23	1202.29	1202.87	0.02
	Waste disposal	1544.78	1544.31	1533.81	1544.61	1554.69	1561.98	1.11
	Biological diversity	780.83	780.75	779.38	780.62	781.81	782.28	0.25
Provisioning services	Food production	206.71	206.69	206.99	207.29	207.44	207.49	0.38
	Raw material production	35.52	35.31	35.34	35.36	35.38	35.41	0.27
Cultural services	Aesthetic landscape	200.15	200.05	197.53	200.03	202.40	204.09	1.97
Total			6362.97	6361.53	6334.77	6362.03	6387.36	6406.83

Table 4 ESV variation of different land uses in Sanjiangyuan nature reserve from 1992 - 2015

Land use	Value/100 million yuan						Change percentage/%
	1992	1995	2000	2005	2010	2015	
Cropland	161.44	161.52	165.07	167.14	167.90	167.30	3.63
Forest	23.00	23.00	23.04	23.04	23.03	23.22	0.94
Grassland	4311.56	4310.95	4306.85	4305.66	4305.32	4307.84	-0.09
Wetland	72.64	72.66	73.28	73.45	73.34	73.81	1.61
Bare areas	15.37	15.44	15.84	15.56	15.30	14.90	-3.07
Water	1778.96	1777.97	1750.69	1777.18	1802.47	1819.77	2.29

Table 5 ESV variations in the different source areas in Sanjiangyuan nature reserve from 1992 - 2015

Source area	ESV/billion yuan						Change rate/%
	1992	1995	2000	2005	2010	2015	
Yellow River	249.281	249.323	250.033	251.345	252.578	253.148	1.55
Yangtze River	331.725	331.538	328.115	329.500	330.805	332.185	0.14
Lancangjiang	54.941	54.941	54.979	55.006	55.002	54.999	0.11

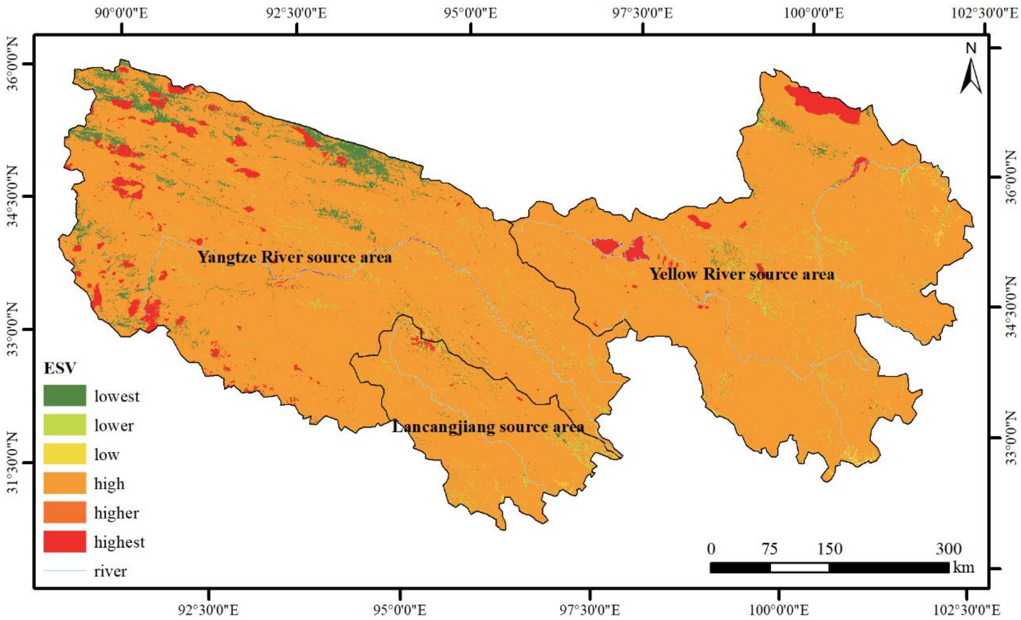

Fig. 5 Distribution of ESV in Sanjiangyuan nature reserve during 2015

bare areas ecosystem were lowest, accounting for 1.15%, 0.36%, and 0.25%, respectively.

Change in the ESV of different ecosystem types

During the study period, the ESV in the study area first decreased and then increased from 2000. From 1992 to 2000, the ESV decreased slightly from 636.297 billion to 633.477 billion yuan, with an average annual decrease of 352 million yuan/year (0.44%). From 2000 to 2015, the ESV increased from 633.477 billion to 640.683 billion yuan, with an average annual increase of 100 million yuan/year (1.14%).

The value of each ecosystem service type in 2015 was higher than that in 1992. In the primary classification of ecosystem services, the values of regulating and supporting services increased by 1.960 billion and 1.944 billion yuan, respectively. The value of cultural services increased the most at 1.97%, while that of provisioning services increased the least, at 0.36%. In the secondary classification of ecosystem services, excluding the aesthetic landscape service, the value of the water supply service increased the most, at 1.848 billion yuan (1.42%), followed by waste disposal service, at 1.72 billion yuan (1.11%), the increase in the value of other ecosystem service types was less than 1%.

Changes in the ESV of different ecosystem services

Overall, the ESVs of cropland, forest, wetland, and water ecosystems increased, while that of grassland ecosystems and bare areas decreased. The ESV of the cropland ecosystem increased most significantly from 16.144 billion yuan in 1992 to 16.73 billion yuan in 2015 (increase of 3.63%), followed by water, with an increase of 4.081 billion yuan (2.29%). However, the ESV of bare areas decreased

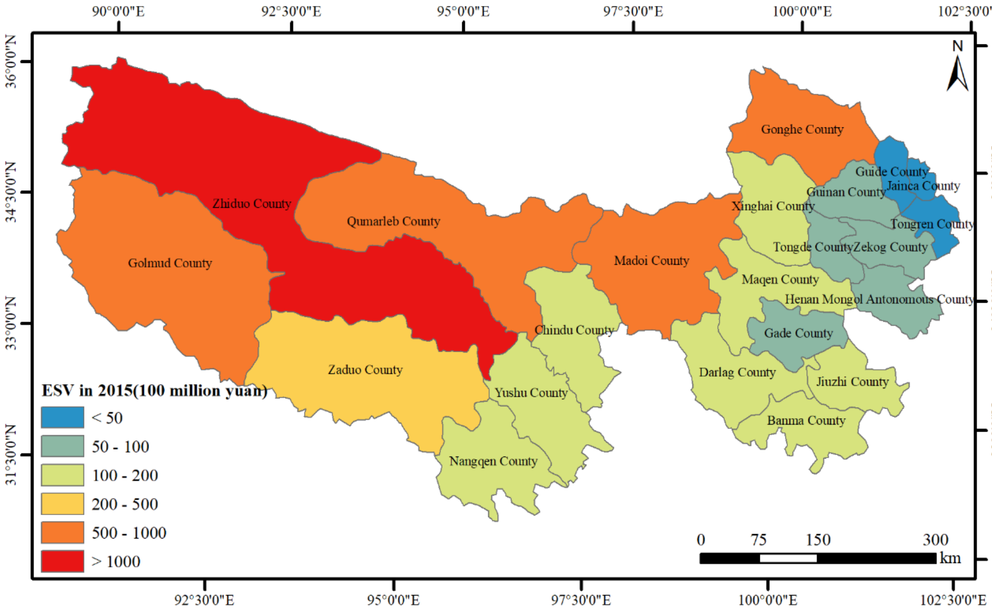

Fig. 6 ESV of every country in Sanjiangyuan nature reserve from 1992 to 2015.

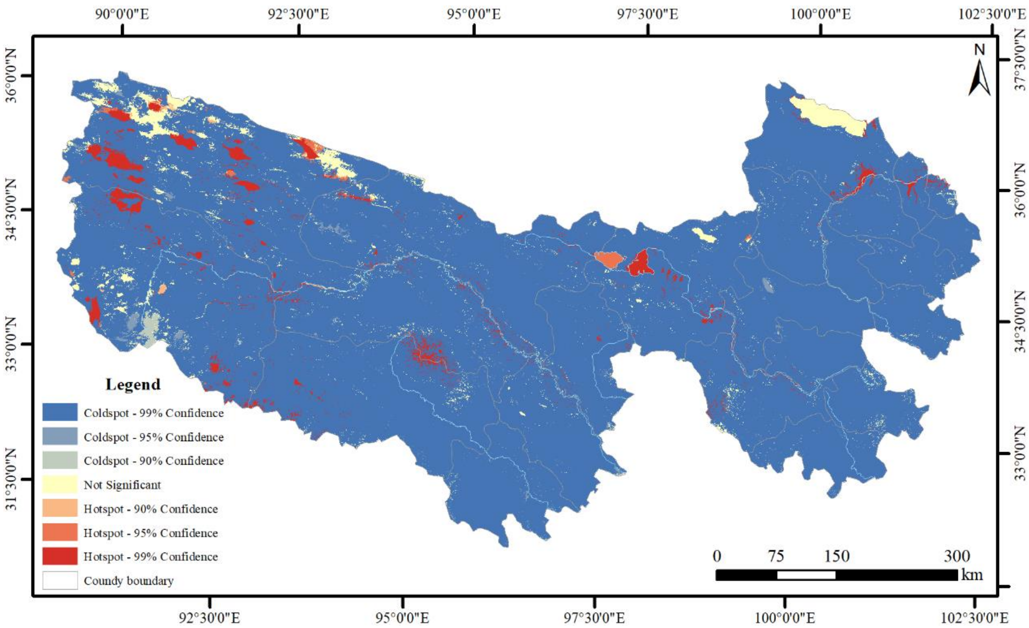

Fig. 7 Annual average ESV hot and cold spots in Sanjiangyuan nature reserve

by 3.07%, while that of grassland ecosystems, the main ecosystem type in the study area, decreased by 372 million yuan (0.09%).

Change of ESV in the different source areas

From 1992 to 2015, the ESVs of each source area increased. The ESV in the Yellow River source area increased by 1.55% from 249.281 billion yuan in 1992 to 253.148 billion yuan in 2015, while that in the Yangtze River source area first decreased and then increased. From 1992 to 2000, the ESV decreased to 328.115 billion yuan, and then increased to 332.185 billion yuan from 2000 to 2015, with an overall change rate of 0.14%. The change rate of ESV in the Lancangjiang source area was the smallest (0.11%), with a total increase of 1.058 billion yuan.

3.2.2 Spatial characteristics

The spatial distribution of the ESV in the study area is shown in Fig. 5. The high- and low-value areas were relatively concentrated, with high-value areas mainly concentrated in water environments, including Qinghai Lake in Gonghe County, Gyaring and Ngoring Lake in Madoi County in the Yellow River source area, and the many lakes in the Tongtian River source area, while low-value areas were mainly concentrated in bare areas distributed in Zhiduo County (northwest of the Yangtze River source area) and Golmud County (south of the Yangtze River source area).

The spatial distribution of ESV in each county during 2015 is shown in Fig. 6, and there were clear spatial

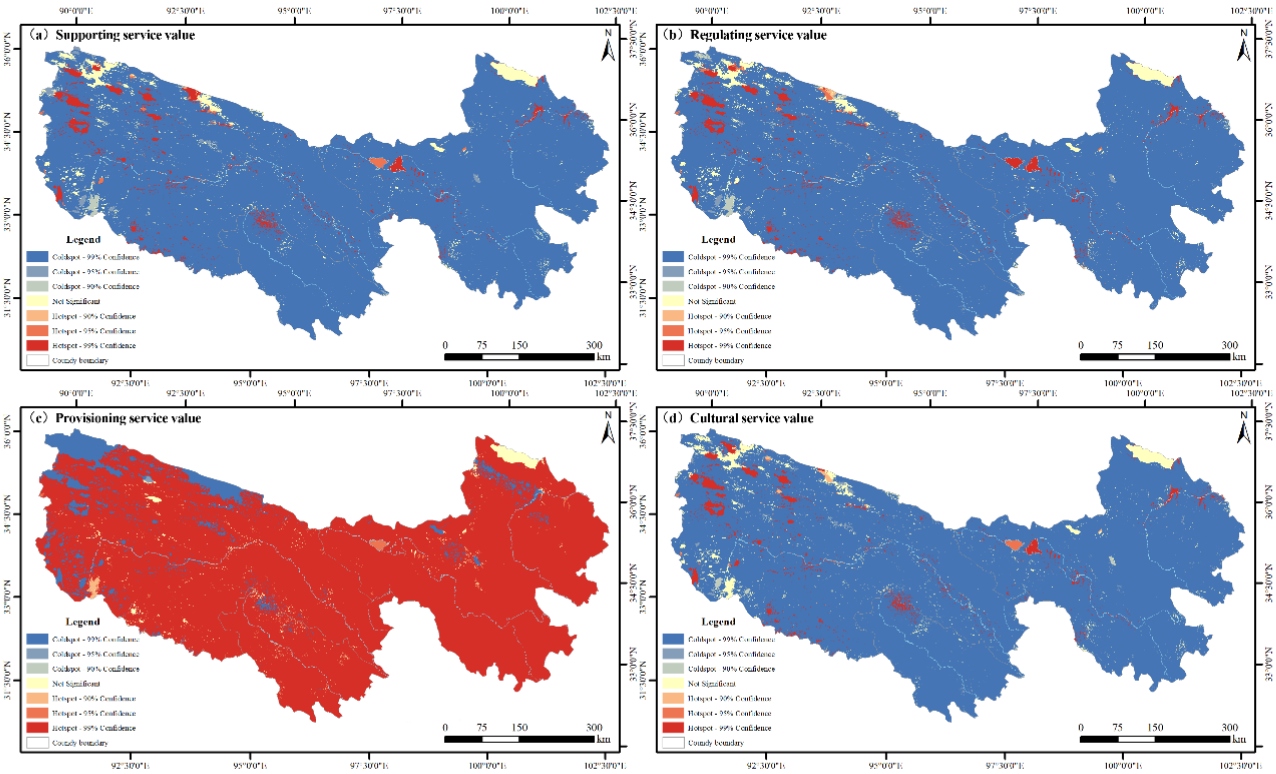

Fig. 8 Hot and cold spots of the annual average values of various ecosystem services in Sanjiangyuan nature reserve

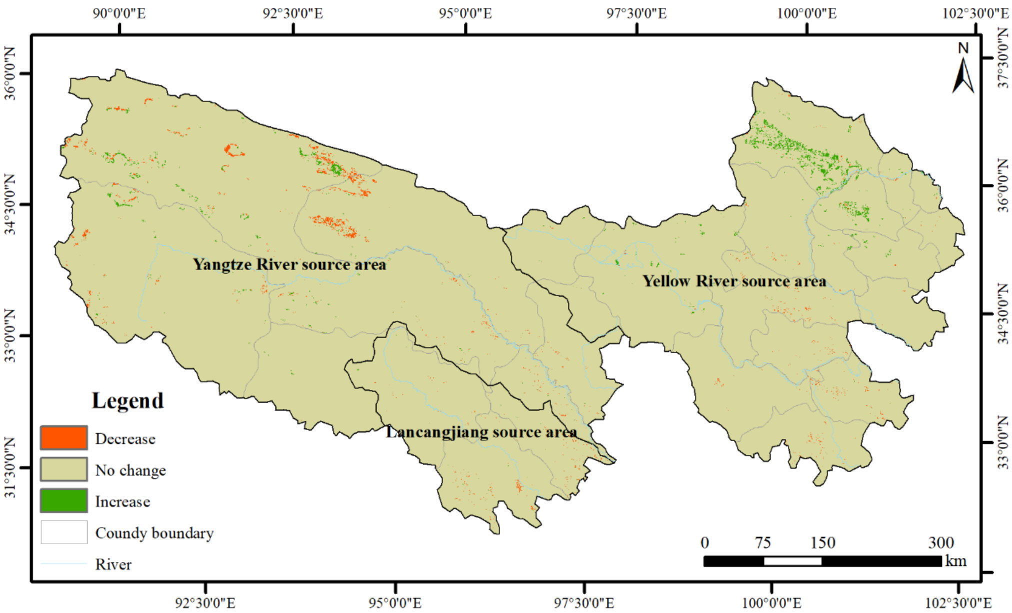

Fig. 9 Trend of ESV in Sanjiangyuan nature reserve

distribution characteristics for each county. Overall, the ESV decreased gradually from east to west, and was lowest in Jainca and Tongren County, located in the west of the study area (2.292 billion and 4.167 billion yuan, respectively). Zhiduo County, located in the west of the study area, exhibited the highest ESV of 149.006 billion yuan. Owing to the relatively high ESV per unit area of water and relatively low ESV per unit area of forest and grassland, excluding bare areas, the ESVs of Zhiduo, Golmud, Qumarleb, and Gonghe County, which contained more lakes, were relatively high, while those in the east and south of the study area were relatively low as they mainly contained forest and grassland.

Spatial distribution of ESV cold and hot spots

We observed and studied the spatial agglomeration of the mean ESVs at the grid level through hotspot analysis, and the result is shown in Fig. 7. Hotspots represent high-value and high-value aggregation areas, while coldspots represent low-value and low-value aggregation areas. In total, 93.31% of the study area belonged to coldspots at a

Table 6 Pearson correlation coefficients between ESV and the driving force indicators

Variable code	x_1	x_2	x_3	x_4	x_5	x_6	x_7
Variable name	permanent resident population	population density	urbanization rate	GDP	the proportion of the primary industry	the proportion of the secondary industry	the proportion of the tertiary industry
Pearson Correlation	-0.680**	0.846**	0.907**	0.889**	-0.594**	0.563**	0.438*
Variable code	x_8	x_9	x_{10}	x_{11}	x_{12}	x_{13}	x_{14}
Variable name	gross industrial value	government revenue	gross output value of agriculture	output value of gross agricultural	output value of gross forestry	output value of gross pastoral	output value of gross fishery
Pearson Correlation	0.879**	0.879**	0.916**	0.904**	0.901**	0.915**	0.667**

Table 7 Regression of the ESV in Sanjiangyuan nature reserve

ESV category	Regression model	R^2
Total value	$y = 0.557x_{10} + 841.372x_3 + 6192.791$	0.965
Regulating service value	$y = 0.266x_{10} - 64.340x_6 + 243.779x_3 + 2360.136$	0.937
Supporting service value	$y = 0.262x_{10} - 62.677x_6 + 245.134x_3 + 3495.003$	0.938
Provisioning service value	$y = 1.332x_2 - 1.511 \times 10^{-7}x_3 + 239.309$	0.911
Cultural service value	$y = 0.056x_{10} - 13.909x_6 + 45.292x_3 + 194.612$	0.933

99% confidence level, while hotspots were mainly distributed along the Yellow River in the east, Madoi County in the center, and Zhiduo and Golmud County in the west, accounting for approximately 2.49% of the study area. The ESVs in the northern part of Gonghe County in the northwest of the study area and the western part of Zhiduo County were insignificant.

The results of the hotspots analysis of primary ESV classification are shown in Fig. 8. The spatial distribution of hot and cold spots of the other three types of ESV was consistent with the total value, excluding the provisioning service value. Based on the land-use types in Fig. 2, we can see that the coldspots were mainly within grassland areas, hotspots were mainly within rivers and lakes, and the insignificant spots were mainly within bare areas. Table 1 shows that the total ESV, and supporting, regulating, and cultural service values per unit area of wetland and water in Sanjiangyuan Natural Reserve were much higher than those of grassland. Therefore, the total ESV and values of the other three services in areas with water indicated that they were hotspots, while grassland areas were coldspots.

Spatial change trend of the ESV

The slope analysis method was followed to simulate the ESV change trend at a pixel scale. Fig. 9 shows that the ESV of the study area did not change significantly during the study period. The area within which the ESV increased was slightly larger than that within which the ESV decreased (2074.01 and 1838.41 km², respectively), accounting for 0.56% and 0.50% of the total area of the study area, respectively. In the Yellow River source area, the ESV was decreasing within an area of 338.99 km², and increasing within an area of 1403.22 km². In the Yellow River source area, the ESV decreased within an area of 338.99 km² and increased within an area of 1403.22 km². In the Lancangjiang source region, the ESV decreased within an area of 179.02 km² and increased within an area of 19.36 km². In the Yangtze River source area, the ESV decreased within an area of 1319.7 km² and increased within an area of 651.04 km².

The ESV mainly increased within Gonghe and Guinan County in the east of the study area. Fig. 3 shows that the land cover of these counties mainly changed from bare areas to grassland and grassland to water, thus, the ESV increased. However, in Zhiduo and Qumarleb County in the Yangtze River source area, located in the west of the study area, the ecosystem types mainly degenerated from grassland to bare areas and the ESV decreased.

3.3 Influencing factors of ESV

3.3.1 Driving factor analysis

The factors driving the spatiotemporal differences in the ESV mainly included natural and human factors. As the changes in the ESV during a short period were mainly affected by human activities (Yao *et al*. 2009, Wang *et al*. 2014a, Luo and Yan 2018, Han *et al*. 2019, Xu *et al*. 2019), climatic factors were ignored and the impacts of human factors were only discussed in this study. The driving factors that may have affected the ESV of Sanjiangyuan Nature Reserve were preliminarily selected based on previous studies and the socioeconomic development status of the study area.

The preliminarily selected driving force indicators included 17 population, economic, and agricultural factors. As some indicators were weakly correlated with the ESV, they were eliminated based on bivariate analysis. The driving force indicators were determined, and are shown in Table 6.

3.3.2 Regression analysis

The driving force factors, total ESV, and values of various services were analyzed by multiple linear regression, and the results are shown in Table 7. The main factors driving the ESV in Sanjiangyuan Nature Reserve included the population density, urbanization rate, proportion of secondary industry, and gross agricultural output value. The total ESV and values of other types of ecosystem services, excluding the provisioning service, were driven by the same factors, including the gross agricultural output value, urbanization rate, and proportion of secondary industry. The regression coefficients for the gross agricultural output value and urbanization rate were positive, while that of the proportion of secondary industry was negative. The population density and urbanization rate were the factors driving the provisioning service value, the regression coefficient of population density was positive, while that of urbanization rate was negative.

The degree of economic development in Sanjiangyuan Nature Reserve is generally low. Primary industry was the main economic structure during the early stage. The proportion of the primary, secondary and tertiary industries respectively was 48.61, 30.03 and 21.36 in 1992. The economy of Sanjiangyuan Nature Reserve was dominated by agriculture, particularly animal husbandry. Farmers and herders adhered to the traditional natural free-range model, which gradually increased the severity of regional grassland degradation. As such, the grassland ecosystem gradually deteriorated and the structure and function of the natural ecosystem became severely damaged. After years of development, secondary and tertiary industries accounted for most of the industry in Sanjiangyuan Nature reserve, with secondary industry becoming dominant. The natural ecosystem in Sanjiangyuan Nature Reserve has a simple structure, poor stability, and weak self-recoverability, and such ecosystems are formed through long-term evolution and development. The ecological damage caused by durative industrial development will hinder the rapid recovery of the natural ecosystem, leading to a decline in the regulating and supporting ability of the ecosystem. Such a decline will also affect the entertainment and cultural attributes of the ecological landscape. In addition, industrial production has greatly accelerated the accumulation of heavy metal elements in the soil, resulting in the surface soil where heavy metals such as Cd, Hg and Zn have reached pollution levels, Washing wastewater produced during coal mining contains micro coal dust, sand, clay, shale, etc., which can also lead to a decrease in water quality and affects water ecological services. Therefore, the proportion of secondary industry in Sanjiangyuan Nature Reserve is negatively related to the regulating, supporting, and cultural service values.

The urbanization rate is typically expressed as the ratio of the number of permanent urban residents to the total population of the region. The increase in the urbanization rate indicated that the rural population of the region moved to more urban areas. The urban population was denser than the rural population. Additionally, with the continuous expansion of the scale of cities and towns, the impacts of production and life on natural ecosystems gradually became concentrated within urban areas, and the degree of fragmentation of grasslands and other natural ecosystems decreased. Therefore, urbanization benefitted the spatial expression of ESV.

The gross output value of agriculture is the total amount of all agricultural, forestry, pastoral, and fishery products, along with the value of all types of service activities supporting these production activities, and reflects the agricultural scale and production level within a certain time period. The increase in the gross agricultural output value indirectly indicated that the agricultural economic strength was significantly enhanced, the quality of life of regional farmers was significantly improved, and farmers had more demand for spiritual and cultural activities, in addition to material goods. Therefore, the increase in the gross agricultural output value positively affected the cultural service value.

Ecosystem provisioning service refers to the products and services provided by the natural ecosystem, and the concepts of provision and demand correspond to one other. Demand for ecosystem services mainly refers to the consumption and use of these services and products by human society. Provision and demand constitute the dynamic process of ecosystem services flowing from natural ecosystems to human society. Population density is the main factor affecting the demand for natural resources. Therefore, as the population density increased, the demand for natural ecosystem services increased, leading to synchronous changes in the provisioning service value. As the regional urbanization level improved, the consumption of resources and energy increased. However, the transformation of land resources by urban expansion damages the natural ecosystem within the urban boundary, resulting in contradictions between regional economic development and the ecological environment, and the gradual degradation of the provisioning service function. Therefore, an increase in the urbanization rate will negatively impact the value of regional provisioning services. In 2015, the urbanization rate of Sanjiangyuan Nature Reserve was 21.09%, which was well below that of Qinghai Province (50.30%) and the national average (56.10%). Therefore, the impact of population density on the provisioning service in the study area was more significant than that of the urbanization rate.

4. Discussion

By comparing characteristics of land use transfer and spatiotemporal changes in ESV, it could be found that the spatial distribution and change characteristics of ESV were strongly correlated with land use. Under the combined impacts of global climate change and human activities, environmental issues in the Yangtze River source area, such as snowline rise, glacier retreat, soil erosion, soil pollution, water pollution, desertification, and grassland degradation, have become prominent. According to the relevant survey data, degraded and desertified grasslands in the source region of the Yangtze River develops at a rate of 2.2% every year, leading to the degradation of grasslands and decrease in the ESV of the corresponding area. In contrast, the

Yellow River source area benefited from the Sanjiangyuan Ecological Protection Project, which effectively curbed the degradation of the ecological environment around the lakes in the area, and restored and reconstructed the natural ecosystem. Thus, the ESV of the corresponding area in the Yellow River source area continued to grow.

Therefore, continuing to conduct ecological protection and construction projects in Sanjiangyuan Nature Reserve, such as restoration of degraded grasslands, restoration of contaminated soil, and treatment of water environment will aid in restoring the natural ecosystem and enhancing the ESV. The gross agricultural output value, urbanization rate and proportion of secondary industry were the main factors driving the ESV in Sanjiangyuan Nature Reserve, which can be improved by moving the rural population, changing the agricultural production mode and closing the mines to reduce the anthropological impacts on the natural ecosystem, particularly those of the agricultural population, to enhance and maintain the ESV.

5. Conclusions

Based on land-use data, changes in land-use transformation in Sanjiangyuan Nature Reserve were analyzed, and the coefficient of the ecosystem service value (ESV) per unit area of China was then corrected using grain yield and net primary productivity data to analyze the spatiotemporal evolution characteristics of the ESV in the study area. Finally, the main factors driving the ESV were discussed by combining the results with socioeconomic statistical data. The results show that grassland was the main type of land use in the study area, accounting for over 90% of the total area. The changes in land use types over the past twenty-four years were mainly due to mutual transformation between grassland and bare areas. Bare areas mainly transformed into grassland in the northern part of the Yellow River source area, while grassland mainly transformed into bare areas in the northwest of the Yangtze River source area. The main type of ESV in the study area was the provisioning service value, accounting for 55.40% of the total value in the study area. Additionally, grassland and water accounted for the largest proportion of the ESV. From 1992 to 2015, the annual average ESV in Sanjiangyuan Nature Reserve was 640.683 billion yuan/year, and first decreased and then increased. Over the past twenty-four years, the ESV increased by 4.386 billion yuan, with an average annual growth rate of 0.69%. The ESV was mainly high in water areas in the Yellow River source area and north of the Yangtze River source area, and was mainly low in the bare areas in the northwest Yangtze River source area. Finally, the gross agricultural output value urbanization rate and proportion of secondary industry were the main factors affecting the ESV in the study area.

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