Chapter 11
Spatial–Temporal Variation Analysis on Ecosystem Service Values in a Typical Inland River Basin, Northwest China

Mingtao Li, Lingfen Kang, and Chuancheng Zhao

Abstract Ecosystem services value (ESV) is a direct manifestation of the change of ecosystem service function and benefits. In this study, we evaluated the value of 11 primary ecosystem services in the upper and middle region of Heihe River Basin (UMHRB) from 2000 to 2018. The spatial–temporal heterogeneity was explored at the grid-scale by using ecosystem service value model, and hot spot analysis. The results showed that: (1) The structure of land use in UMHRB was dominated by unused land, followed by grassland, farmland, forestland, water area and built-up land. The change trend of land use was the decrease of unused land and grassland, and the increase of built-up land, water area, farmland and forest land. (2) The temporal evolution of total ESV in UMHRB had shown a steady upward trend from 2000 to 2018. Among the ecosystem types, grassland and water area contributed the most to ESV. The trend of ESV changes showed that the ESV of unused land, grassland and forestland decreased, while the ESV of built-up land, farmland and water increased. For each individual ESV, hydrological regulation and climate regulation had the largest ESV contribution. Only the ESVs of climate regulation have slightly decreased, while other ecosystem services have increased. (3) The spatial distribution of ESV in UMHRB showed a spatially clustered distribution pattern and the degree of clustering was slightly weakened. From 2000 to 2018, the hot spots were mainly distributed in the southern Qilian Mountains, and sporadically scattered near reservoirs and rivers in the northern region. The cold spots were concentrated in the northern part near the desert area.

Keywords Ecosystem service values · Spatial–temporal variation · Heihe River Basin

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11.1 Introduction

Ecosystem service refers to the goods and services obtained directly or indirectly through the structure, process and function of ecosystem (Wei et al. 2016). It has a key role in maintaining human well-being and sustainable regional development, and has become a hot area of interest in ecology and geography (Duan et al. 2012). Ecosystem services value (ESV) is both a core indicator of ecosystem services and an important tool for assessing the effectiveness of ecological conservation (Guan et al. 2018; Huang et al. 2018). Daily (1997), Costanza et al. (1997) proposed the connotation and value evaluation method of ecosystem services, which laid the theoretical foundation for the valuation of ecosystem services. Ouyang et al. (1999) and Xie et al. (2015) proposed a methodology for valuing ecosystem services in China based on the results of Costanza's study. Based on this, many scholars have done a lot of research on the quantitative measurement of the value of terrestrial ecosystem services in China at different regions, different land types and different spatial scales, including correction of equivalent factors, sensitivity analysis, spatiotemporal distribution pattern and influencing factor analysis (Ding et al. 2020; Geng et al. 2020; Qiao et al. 2020; Wang and Ma 2020).

The Heihe River Basin is located in the inland area of northwest China, with a very fragile ecological environment. This paper reveals the main characteristics of regional land use changes from 2000 to 2018, based on land use data from 2000, 2015 and 2018, in the middle and upper reaches of the Heihe River basin. The spatial–temporal heterogeneity and spatial autocorrelation patterns of ESV were explored at the grid-scale and county-scale by using the modified ESV equivalent, ESV assessment models, and hot spot analysis. The results of the study will provide a theoretical basis for the construction of the ecological barrier zone and the sustainable development of the ecological environment in the Hexi Corridor, China.

11.2 Materials and Methods

11.2.1 Study Area

The middle and upper reaches of the Heihe River Basin (UMHRB), covering an area of 98,900 km^2, is located in Gansu and Qinhai Province, China (96°08′—101°37′E, 37°41′—42°45′N) (see Fig. 11.1). The topography of the basin is complex, with the terrain sloping from southeast to northwest. The upstream region is located in the Qilian Mountains, with high and steep mountains. The midstream region has a lower topography and consists of basins and corridor plains. The climate of Heihe River Basin has obvious zonal and regional characteristics. The upstream area has an annual average temperature of less than 2 °C and an annual precipitation of 350 mm, while the midstream area has an annual average temperature of 6~8 °C and an annual precipitation of 140 mm. The major land use types of UMHRB are

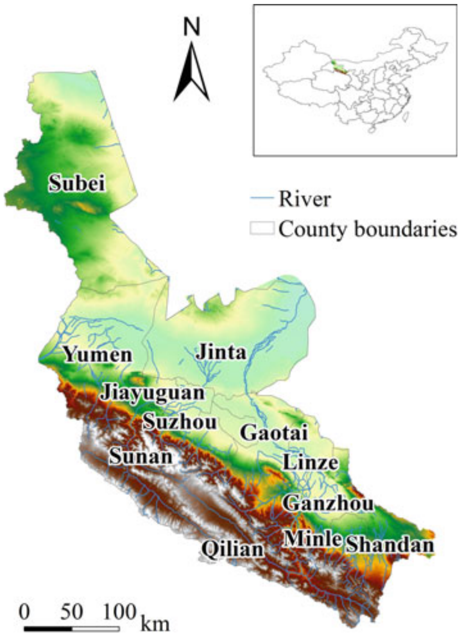

Fig. 11.1 Location of the UMHRB region

farmland, forestland, grassland, built-up land, water, and unused land. The upstream area of Heihe River Basin is dominated by grassland and forestland, which is the runoff formation area of Heihe River, while the midstream area is dominated by oasis, which is an important irrigated agricultural area. Due to the rapid transformation of regional land use, ecosystem structure and function have been greatly affected, resulting in changes in the spatial and temporal distribution of ESVs.

11.2.2 Data Sources

Land use data with a spatial resolution of 30 m in 2000, 2010 and 2018 were acquired from the Resource and Environmental Science Data Center of the Chinese Academy of Sciences (http://www.resdc.cn). Six primary classes of land use types (farmland, forestland, grassland, built-up land, water, and unused land) are classified according to the actual land use characteristics of the study area. Agricultural products were obtained from Gansu and Qinhai Statistical Yearbook.

11.2.3 Ecosystem Service Assessment Model

The ESV equivalent per unit area in the study area was corrected using crop yields and food prices with reference to the research results of Xie et al. (2015) (see Table 11.1). In order to study the spatial characteristics of ESV, the study area was divided into 1 × 1 km grid scale. The calculation formula is as follows:

$$\mathrm{ESV} = \sum_{i=1}^{n} (U_i \cdot VC_i) \quad (11.1)$$

where ESV represents the total ecosystem services value in the study area (yuan). VC_i is the ESV of 1 standard unit equivalent factor (yuan/hm^2). U_i is the i type land area in the study area.

Table 11.1 Ecosystem service value equivalent per unit area of different land use in UMHRB

Type of service		Ecological service value					
		Farmland	Forestland	Grassland	Water	Built-up land	Unused land
Provisioning service	Food production	1809.16	404.40	808.80	1702.74	0.00	42.57
	Raw material	830.08	915.22	1191.92	48,953.66	0.00	63.85
	Water supply	42.57	468.25	659.81	17,644.60	0.00	42.57
Regulating service	Gas regulation	1426.04	3001.07	4192.99	1638.88	0.00	234.13
	Climate regulation	766.23	9003.22	11,089.07	4874.08	0.00	212.84
	Waste treatment	212.84	2724.38	3660.88	11,812.73	0.00	659.81
	Hydrological regulation	574.67	7130.21	8130.56	217,609.66	0.00	446.97
Supporting service	Soil conservation	2192.27	3660.88	5108.21	1979.43	0.00	276.69
	Nutrient cycling	255.41	276.69	383.12	148.99	0.00	21.28
	Biodiversity protection	276.69	3341.62	4639.96	5427.47	0.00	255.41
Cultural service	Recreation and culture	127.71	1468.61	2043.28	4022.71	80.57	106.42

11.2.4 Hot Spot Analysis

Hotspot analysis Gi* index was used to identify spatial clusters with statistically significant high values (hot spots) and low values (cold spots), which can effectively reveal the spatial heterogeneity of ESVs. The calculation formula is as follows:

$$G_i{}^* = \frac{\sum_{j=1}^{n} w_{ij}x_{ij} - \bar{x}\sum_{j=1}^{n} w_{ij}}{s\sqrt{[n\sum_{j=1}^{n} w_{ij}^2 - (\sum_{j=1}^{n} wij)^2]/(n-1)}} \tag{11.2}$$

where w_{ij} is the spatial weight, x_{ij} is the observed values of the ESV evaluation unit, n is the total number of ESV evaluation units at a given scale in the study area. The higher the Z score of $G_i{}^*$ index, the more obvious the clustering of hot spot areas, while the lower the score, the more obvious the clustering of cold spots.

11.3 Results

11.3.1 Land Use Change from 2000 to 2018 in UMHRB

From 2000 to 2018, unused land and grassland were the two primary land use types in UMHRB, accounting for more than 86% of the total area, while other land use types accounted for only a small proportion (see Fig. 11.2). The change trend of different land use types in the study area is as follows: the area of unused land and grassland gradually decreased, the area of built-up land, water area, forest land and farmland gradually increased.

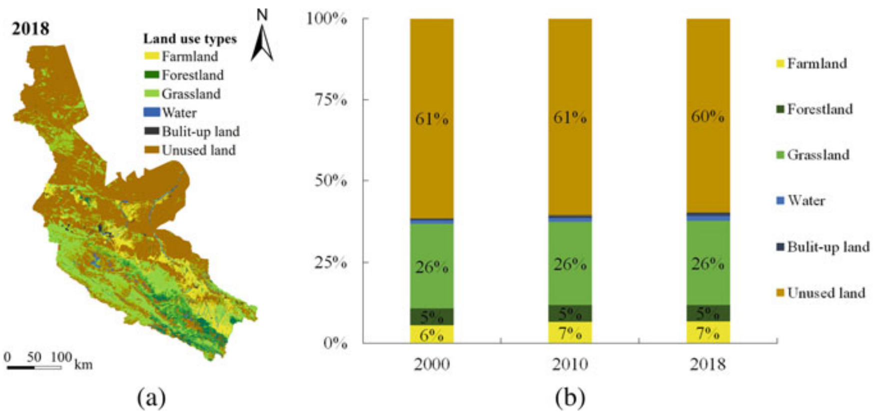

Fig. 11.2 Land use types of UMHRB in 2018 (**a**) and proportions from 2000 to 2018 (**b**)

11.3.2 Spatial–Temporal Variation of ESV in UMHRB

Characteristics of temporal development

As can be seen from Table 11.2, the ESV of UMHRB presented an upward trend from 2000 to 2018, from 1808.22 × 10^8 yuan to 1889.66 × 10^8 yuan, with an increase of 4.50% and an average annual increasing rate of 0.25%. The increase from 2000 to 2010 was slow, increasing by only 1.23%, while the increase from 2010 to 2018 was larger, increasing by 3.24%. It indicates that there was a trend of ecosystem improvement in the middle and upper reaches of the Heihe River Basin.

Among the ecosystem types, grassland and water contributed the most with 57.29% and 23.43%, respectively, while built-up land contributed the least with 0.004%. Although water area account for a small proportion of the total study area, it contributed more to the ecosystem services of the basin. As a typical inland river basin in the arid zone, increasing the watershed area has an important positive effect on improving the regional ecological environment and ecosystem services.

The change trend of ESV of different land use types is as follows: the ESV of unused land, grassland and forestland declined, and the ESV of built-up land, farmland, and water increased. The ESV of built-up land was increasing at the fastest rate, with an increment rate of 59.15% and an average annual increasing rate of 4.17%. The conversion of desert and grassland to farmland and built-up land due to urbanization and irrigated agriculture is the primary reason for the change in ESV of different land types.

The most dominant ecological service in the UMHRB is the regulating service, accounting for 66.41%, followed by the supporting service, provisioning service, and cultural service. In the regulating services, the ESV of hydrological regulation were the largest, accounting for 30.81% of the total ESV. Followed by climate regulation, which accounting for 18.91%. There are two national nature reserves in the study area, Qilian Mountain and Heihe River, with abundant forest resources and water systems, which enhance the functions of hydrological regulation and climate regulation.

Table 11.2 Change of ESV in UMHRB from 2000 to 2018

Land use types	ESV/(10^8 Yuan·a^{-1})			Change rate of ESV (%)	Average annual increasing rate (%)
	2000	2010	2018		
Farmland	47.25	56.30	57.14	20.93	1.16
Forestland	166.42	165.92	166.38	−0.03	0.00
Grassland	1090.31	1072.04	1082.64	−0.70	−0.04
Water	359.68	393.56	442.72	23.08	1.28
Built-up land	0.04	0.05	0.07	59.15	4.17
Unused land	144.52	142.52	140.72	−2.63	−0.15
Total	1808.22	1830.40	1889.66	4.50	0.25

From 2000 to 2018, only the ESVs of climate regulation have slightly decreased, while other ecosystem services have increased. The ESV of raw material production, water supply and hydrological regulation increased faster, by 13.52%, 10.58% and 10.57% respectively. The construction of ecological projects such as natural forest protection and return of cultivated land to forest has increased the area of forest land in the study area. The water connotation function of forest land is the main reason for the increase of the ESV of these three ecosystem services (Table 11.3).

Characteristics of spatial variation

The spatial distribution of ESVs at the 1-km grid scale from 2000 to 2018 was shown as Fig. 11.3. The spatial variation of ESVs in UMHRB showed a decreasing spatial pattern from the Qilian Mountains to the corridor plains. From 2000 to 2018, the high-value area was stably distributed in the Qilian Mountains, whose vegetation cover was dominated by woodlands and grasslands, with a good ecological environment. Meanwhile, a medium–high value aggregation zone was formed along the main stream of the Heihe River, under the influence of the distribution of water in the region. The low-value areas were mainly located in the midstream plains and desert areas, which were more disturbed by human activities and dominated by farmland, built-up land and unused land, with relatively poor ecological environment.

Table 11.3 The individual ESVs in UMHRB from 2000 to 2018

Ecosystem service	ESV/(10^8 Yuan·a^{-1})			Change rate of ESV (%)	Average annual increasing rate (%)
	2000	2010	2018		
Food production	37.70	39.42	40.03	6.19	0.34
Raw material	99.98	105.52	113.49	13.52	0.75
Water supply	42.51	44.11	47.01	10.58	0.59
Gas regulation	148.61	148.23	149.55	0.63	0.04
Climate regulation	357.57	353.76	357.36	−0.06	0.00
Waste treatment	164.23	163.53	165.85	0.99	0.05
Hydrological regulation	526.53	546.45	582.19	10.57	0.59
Soil conservation	183.05	183.08	184.73	0.92	0.05
Nutrient cycling	14.28	14.38	14.51	1.62	0.09
Biodiversity protection	161.22	159.81	161.71	0.30	0.02
Recreation and culture	72.55	72.12	73.23	0.94	0.05

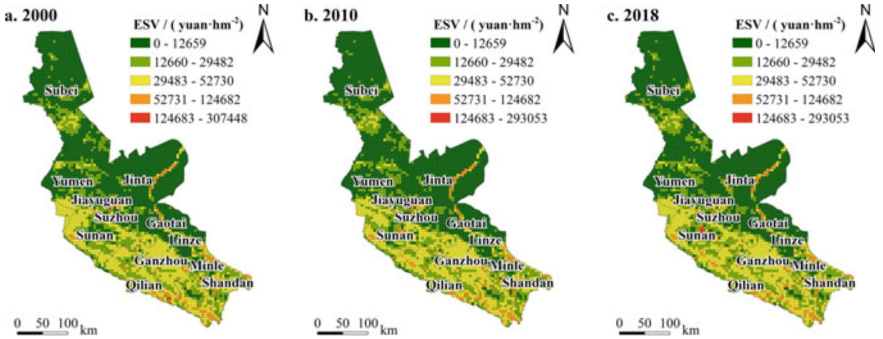

Fig. 11.3 Spatial distribution of ESV in the UMHRB from 2000 to 2018

In 2000, the high-value areas of unit area ESV mainly distributed in Qilian and Minle, and low-value areas primarily distributed in Subei, Yumen, and Jinta. Compared with 2000, there was no significant change in the high value area and the low value area in 2010. In 2018, the high-value areas decreased and were mainly concentrated in Qilian County. The development of urbanization in the region had led to the encroachment of built-up land on farmland and grassland.

Hotspot analysis showed that the spatial distribution pattern of hot and cold spots of ESV in UMHRB remained basically stable from 2000 to 2018 (see Fig. 11.4). The hot spots were mainly distributed in the southern Qilian Mountains, and sporadically scattered near reservoirs and rivers in the northern region. The cold spots were concentrated in the northern part near the desert area, while the rest of the area had no obvious spatial clustering characteristics. In 2000, the spatial concentration of ESV was most pronounced. Compared with 2000, the changes of cold spots and hot spots were not obvious in 2010, and some hot spots in southern area of Subei became insignificant, while hot spots in western area of Sunan increased. In 2018, the hot spots and cold spots showed a shrinking trend compared with the previous stage. The

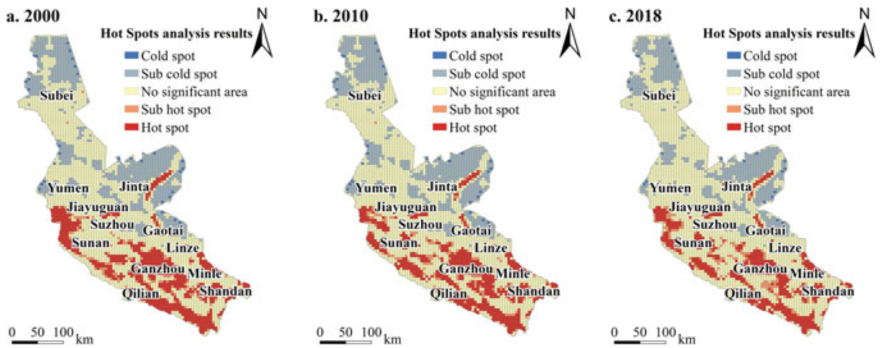

Fig. 11.4 Spatial clustering of ESV in UMHRB from 2000 to 2018

hot spots in Sunan were greatly reduced, while the secondary cold spots in Yumen gradually disappeared and became non-significant areas.

11.4 Conclusions

The structure of land use in UMHRB was dominated by unused land, followed by grassland, farmland, forestland, water area and built-up land. The change trend of land use was the decrease of unused land and grassland, and the increase of built-up land, water area, farmland and forest land.

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