International Journal of Geo-Information

MDPI

Article

The Spatial and Temporal Characteristics of Ecosystem Service Trade-Offs and Synergistic Relationships in a Mountainous Region of Northern China

Xianglong Hou [1,†], Hui Yang [2,†] and Jiansheng Cao [2,*]

[1] Institute of Geographical Sciences, Hebei Academy of Sciences, Hebei Technology Innovation Center for Geographic Information Application, Shijiazhuang 050011, China
[2] Key Laboratory of Agricultural Water Resources, Hebei Key Laboratory of Agricultural Water-Saving, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang 050001, China
* Correspondence: caojs@sjziam.ac.cn
† These authors contributed equally to this work.

Abstract: Understanding ecosystem service trade-offs and synergies is the foundation for achieving the efficient management of the ecosystem and improving human well-being. Therefore, in this paper, multi-scale trade-offs and synergies among eleven secondary ecosystem service (ES) types of four ecosystem service categories in the mountainous areas of North China in 2015 are assessed using statistical methods and spatial analysis, and their driving factors are analyzed, including natural factors and socioeconomic factors. The results show that for the study area, only the raw material production service and nutrient cycle maintenance service, water supply service and hydrological regulation service, environmental purification service and biodiversity maintenance service, environmental purification service and aesthetic landscape service, and biodiversity maintenance service and aesthetic landscape service show extremely strong synergistic correlations at four spatial scales. The spatial autocorrelation among services at different scales is basically consistent with the statistical correlation, but the degree of correlation varies. Unlike the grid, township, and county scales, all service pairs are spatially autocorrelated across the study area at the land use type scale, and the clustering characteristics are more obvious and similar. All service pairs are synergistic with low–low values at the mountain–plain junction in the Taihang Mountain (THM) and in the northern part of the Bashang region (BSR). The spatial trade-offs and synergies of the regulating and maintenance services in the study area are closely related to the spatial distribution of land use types. The main natural influence on the synergistic trade-offs of ecosystem services (ESs) at the township scale is elevation, while socioeconomics are mainly influenced by population and GDP. This study can contribute to strengthening decision makers' understanding of the spatial scales of ES relationships in mountain areas and the extent to which different natural and socioeconomic factors influence them.

Keywords: ecosystem service; trade-off/synergy; climate; vegetation; soil; socioeconomic factors

check for updates

Citation: Hou, X.; Yang, H.; Cao, J. The Spatial and Temporal Characteristics of Ecosystem Service Trade-Offs and Synergistic Relationships in a Mountainous Region of Northern China. *ISPRS Int. J. Geo-Inf.* **2024**, *13*, 458. https://doi.org/10.3390/ijgi13120458

Academic Editors: Wolfgang Kainz and Godwin Yeboah

Received: 13 September 2024
Revised: 6 December 2024
Accepted: 9 December 2024
Published: 17 December 2024

Copyright: © 2024 by the authors. Published by MDPI on behalf of the International Society for Photogrammetry and Remote Sensing. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Ecosystem services (ESs) are the benefits that humans derive from ecosystems [1], including material goods or environmental services [2]. ESs build a channel that connects humans to nature [3]. ESs include provisioning, regulating, supporting, and cultural services [4], but natural conditions and human needs make ESs exhibit trade-offs between the two or synergistic relationships with the same trends. Identifying the inter-relationships among ESs, clarifying the change characteristics and driving mechanisms of each relationship, and enhancing the understanding of the various relationships can improve the overall benefits of ecosystems, ensure the sustainable provisioning of ESs, and contribute to the benign development of human society [5–7].

In view of the important research value of the relationship between ecosystem service (ES) trade-offs and synergies, researchers from various disciplines, such as ecology, economics, and geography, have carried out relevant studies [8–11] and analyzed trade-offs and synergistic relationships using various methods, such as statistical analyses [12–14], spatial autocorrelation and principal component analysis [15,16], spatial mapping [17], multi-scenario simulation [18,19], spatiotemporal statistics with image-by-image partial correlation analysis [12], and many other methods. More models have been developed that help identify relationships among ESs, such as InVEST, ARIES, ESValue, EcoAIM, EcoMetrix, NAIS, SolVES, and other models [20–23]. The spatial and temporal performance characteristics, scale effects, formation mechanisms, and uncertainties of ES trade-offs/synergies have been studied [12,24].

ES relationships are generally influenced by various aspects, such as climatic conditions, vegetation types, topography and geomorphology, land use practices and management measures, urbanization, and ecological engineering [25]. ES trade-offs and synergistic relationships are spatial and temporal scale-dependent; the global scale is not representative of ES relationships at a more micro-scale [26]. At different spatial scales, ES trade-offs and synergistic relationships may change. In general, at large and medium scales, climate, vegetation type, topography, geomorphic features, urbanization, and ecological engineering are the main drivers of changes in ES inter-relationships, while at small scales, the main drivers are differences in land use practices and management measures. Currently, the key drivers of changes in ES relationships include climate change, ecological engineering, and urbanization [27]. Humans tend to select ESs in favor of provisioning services that bring direct economic value and neglect other regulating and supporting services that bring long-term benefits to social development, intensifying the conflict between socioeconomic development and ecological and environmental protection [28]. In the context of rapid population and economic growth and increasing resource scarcity in the world, studying the trade-offs and synergies of ES has significance in addressing global climate change and curbing the deterioration of regional ecological environments so as to realize win–win situations for ecological protection and social development [27]. However, current research involving the driving mechanism of ES trade-offs/synergies under natural and socioeconomic factors is still limited, as the same inputs have varying impacts on different ESs, and changing scales can alter the dominant drivers and biophysical linkages of ESs, affecting their relationships. For example, trade-offs between food supply and habitat quality rose from the grid to village level on the Loess Plateau [29]. Depending on the scale at which the intervention and management effort is made, the ensuing trade-offs and synergies among services can vary, but such interactions are mostly unexplored. As a result, the relationships between ESs need to be clarified further [30].

A variety of important ESs to humanity were provided by mountain ecosystems [1,31], including climate regulation, purification, and nutrient cycling services [32,33]. Approximately 56% of China's population depends on mountain resources [34]. Therefore, it is necessary to explore the distribution patterns of ES values in mountainous areas. Regional ecosystems are always influenced by natural and socioeconomic factors, and the identification of trade-offs and synergies, drivers, and mechanisms of ESs is a prerequisite for clarifying ES management [35]. Thus, in this study, the mountainous area of North China was chosen as the study area, which is the water conservation area and the main ecological security barrier in Northern China. Additionally, North China's mountains are also the only natural ecosystem that China's Beijing–Tianjin–Hebei region can rely on to achieve carbon neutrality [36]. The objective of this paper is to conduct a comparative analysis of trade-offs/synergies between multiple ecosystem services at smaller spatial scales, such as those of counties and townships, as well as research on the factors that influence them. Specifically, (1) based on the correlation relationship analysis and spatial correlation, the spatial scale changes in ES trade-offs and synergistic relationships is explored to identify the dependence of trade-offs and synergies among eleven secondary ES types of four ES categories (provisioning, regulating, culture, and supporting services) on spatial scale.

(2) The natural and socioeconomic influencing factors are studied at the grid, township, county and land use type levels to figure out the driving factors. Based on the multiple non-linear relationships of ESs, the analysis of the types of ES trade-offs, spatial patterns and scale effects of their formation mechanisms will help provide scientific support for effective decision making and management and can guarantee the coordination and orderliness of ecosystems as well.

2. Materials and Methods

2.1. Study Area

The study area is located in N36°14′0″–42°38′10″, E113°30′0″–119°34′40″, including three regions, with an area of 12.18 × 10^4 km^2, namely, the Taihang Mountain (THM), accounting for 24% of the total area, the Yanshan Mountain (YSM), accounting for 51.4% and the Bashang region (BSR), accounting for 24.6%, respectively. Most of the rivers in the Hai River Basin originate in the study area (Figure 1). The region has a typical warm temperate continental monsoon climate, with an average annual temperature of 11 °C and average annual precipitation of 500 mm [35]. Secondary forest *Robinia pseudoacacia* L. and scrubs Vervain Family and wild jujube are the typical vegetation types. The overlying soil constituted of gravel is thin and the underlying rock layer is mainly a weathered layer of gneiss [37].

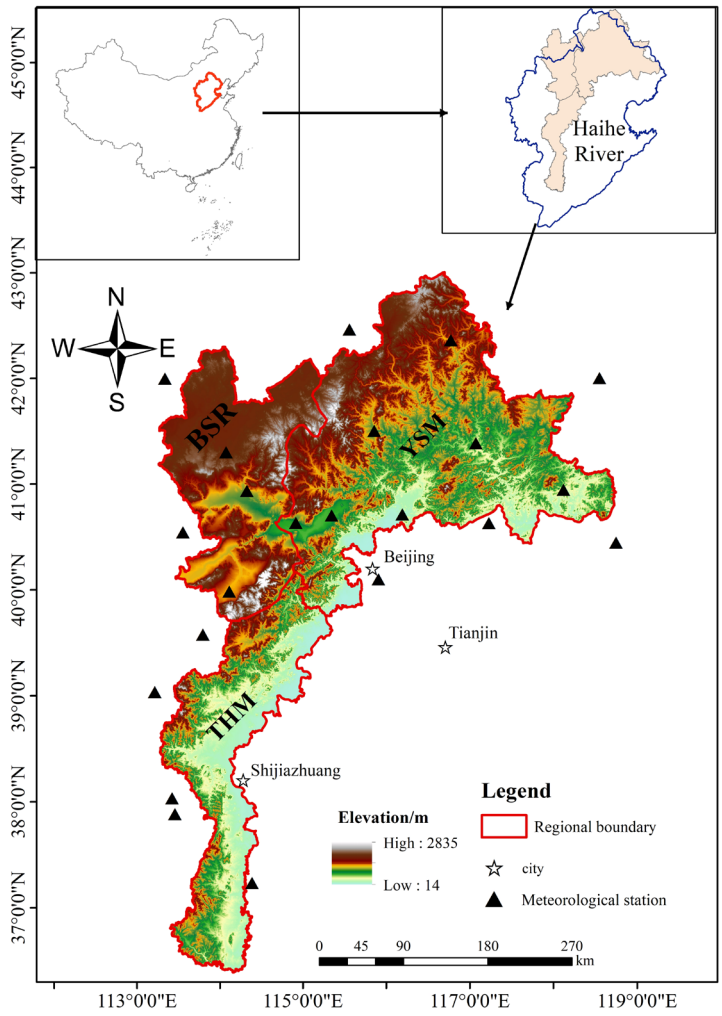


Figure 1. Location of the study area.

2.2. Data

We used datasets reflecting natural and socioeconomic factors. Natural factors include climate, topography, soil and vegetation, and socioeconomic factors include land use intensity, population density, economic density and Gross Domestic Product (GDP) per capita. Climate change is quantified in terms of precipitation and reference evapotranspiration (ET_0), calculated by meteorological data. Meteorological data included daily precipitation, sunshine duration, minimum/maximum temperature, wind speed and sunshine duration in 2015 are from 22 meteorological stations located in and around the study area (Figure 1) which were provided by the National Meteorological Administration of China (http://data.cma.cn accessed on 8 December 2024).

The topography data include elevation, slope and aspect, which are obtained by calculating with Arc GIS 10.5 using DEM data with a spatial resolution of 90 m collected from the Geospatial Data Cloud of China (http://www.gscloud.cn/ accessed on 8 December 2024). For computational uniformity, the DEM data were resampled into a spatial resolution of 1 km, with the rater processing tool in Arc GIS 10.5.

Soil organic carbon fractions data were derived from the Harmonized World Soil Database, provided by the Cold and Arid Regions Sciences Data Center (http://westdc.westgis.ac.cn accessed on 8 December 2024) Surface vegetation cover is reflected by the Normalized Difference Vegetation Index (NDVI). The NDVI and land use data in 2015 with a 1 km spatial resolution and the data of township and county boundaries were downloaded from the Resources and Environmental Sciences Data Center (RESDC), Chinese Academy of Sciences (http://www.resdc.cn accessed on 8 December 2024).

The spatial distribution data of population and GDP in 2015 with a resolution of 1 km were extracted from the Spatial Distribution of Population in China Kilometer Grid Dataset [38] and the Spatial Distribution of GDP in China Kilometer Grid Dataset [39], respectively. The data of terrestrial ES values, in units of 10^4 Chinese Yuan (CNY)/km^2, with a resolution of 1 km in 2015 were extracted from the Spatial Distribution of Terrestrial Ecosystem Service Values in China Dataset [40]. The calculation method was shown in Yang et al. [37].

Spatial distribution of the study area was obtained using ordinary kriging interpolation of Arc GIS 10.5 for precipitation, temperature and ET_0 data, and the spatial resolution was also 1 km to match soil and other data.

2.3. Method

2.3.1. Reference Evapotranspiration

Reference evapotranspiration (ET_0) is calculated using the 'modified Hargreaves' equation as follows [41], which generates superior results than the Pennman–Monteith method when information is uncertain. The calculations of relevant parameters are refereed to Allen et al. [42].

$$ET_0 = 0.0013 \times 0.408 \times RA \times (T_{av} + 17) \times (TD - 0.0123P)^{0.76} \quad (1)$$

where RA is extraterrestrial radiation, in MJ·m^{-2}·d^{-1}, T_{av} is the average of daily maximum and minimum temperatures, in °C, TD is the difference between daily maximum and minimum temperatures, in °C, and P is the daily precipitation, in mm.

2.3.2. Calculation of Socioeconomic Factors

Land use intensity is a direct expression of the human–land relationship, quantifying the extent to which human activities interfere with the land landscape [43]. A comprehensive land use intensity index L is calculated as follows.

$$L = \sum_{i=1}^{n} A_i \times C_i \quad (2)$$

where A_i is the graded index of land use intensity at land use type i in sampling area, C_i is the percentage of area of graded land use intensity at land use type i in sampling area,

namely, $C_i = S_i/S$, S_i is the area of land use type i in sampling area, in km^2, S is the total area of sampling area, and n is grading index of land use intensity for different land use types (Table 1, according to Zhuang and Liu [44]).

Table 1. Grading index of land use intensity for different land use types.

Land Use Type	Unutilized Land, Bare Land	Woodland, Grassland and Water Body	Farmland and Garden	Construction Land
Grading index	1	2	3	4

Sample collection of spatial land use data is carried out using an equiproduct grid covering the whole region. Considering the grid size of land use map, in this paper, a 3 km × 3 km grid is used for systematic sampling. The irregular parcels cut at the edges of the study area with an area of less than 0.5 regular sample areas are merged into the adjacent regular sample areas.

Population density is the number of populations divided by area, which characterizing the population carrying pressure per unit of land area. Economic density is GDP per unit area, indicating the degree of economic development of the corresponding region. GDP per capita is GDP divided by the number of populations, indicating the level of socioeconomic development [45].

2.3.3. Correlation Analysis of ES Values

Statistical correlation analysis qualitatively identifies the relationship and degree of relationship of ESs. To ensure comparability of results, Spearman's correlation analysis was used to determine trade-off/synergistic relationships between paired ESs [30]. When the correlation coefficient R between two ESs is positive, they are considered synergistic; when R is negative, they are trade-offs [46]. And the p value reflects the significance of the relationship. In this paper, R is classified into seven levels (Table 2). We estimated the statistical correlation analysis with IBM SPSS Statistics 20.

Table 2. The relevance classification level between ES values.

Relevance Classification Level	R	p
No relationship	—	>0.10
Synergy **	>0	<0.01
Synergy *	>0	0.01–0.05
Synergy	>0	0.05–0.10
Trade-off	<0	0.05–0.10
Trade-off *	<0	0.01–0.05
Trade-off **	<0	<0.01

* significant; ** very significant.

2.3.4. Spatial Analysis of ES Values

Spatial autocorrelation characterizes the correlation trade-offs/synergies between services and reveals the extent of clustering and spatial patterns [47,48]. In general, spatial heterogeneity of the regional elements prevails [49]. Therefore, local spatial autocorrelation analysis becomes the key to accurately grasp the spatial heterogeneity of local elements, and is used to reflect the degree of correlation between the ES values of a region is correlated with its neighboring regions. Anselin [50] proposed the Local Moran statistic as a method to identify local clusters and local spatial outliers, which is the Local Indicators of Spatial Association (LISA). Local Moran's I is calculated as,

$$I = z_i \sum_{j=1}^{n} W_{ij} z_j \quad (3)$$

where n is the number of samples, z_i and z_j are the standardized statistic of the observations in regions i and j, respectively, and W_{ij} is the spatial weight matrix.

In this paper, we used the bivariate Local Moran's I of GeoDa 1.20 to analyze spatial autocorrelation of ESs at different spatial scales in the study area in 2015. Through the software tool, three maps can be obtained, including the cluster map, the significance map and the Moran scatter plot. The cluster map expands the significant locations with an indication of the type of spatial association based on the location of the values and their spatial lag in the Moran scatter plot. The significance map shows the locations with a significant local statistic, which includes p value at 0.05, 0.01, 0.001 and 0.0001, and shows all the categories of significance that are meaningful for the given number of permutations. The Moran scatter plot shows the I value scatter plot of two variables, if $I < 0$, it represents a negative correlation between two variables, and $I > 0$, it stands for the two variables are positively correlated, and the larger the absolute value of I, the stronger the correlation.

Further, Microsoft Excel 2016 was also used to process and analyze the data.

3. Results

3.1. Spatial Pattern of ESs

The eleven ES categories exhibited their spatial distribution characteristics (Figure 2).

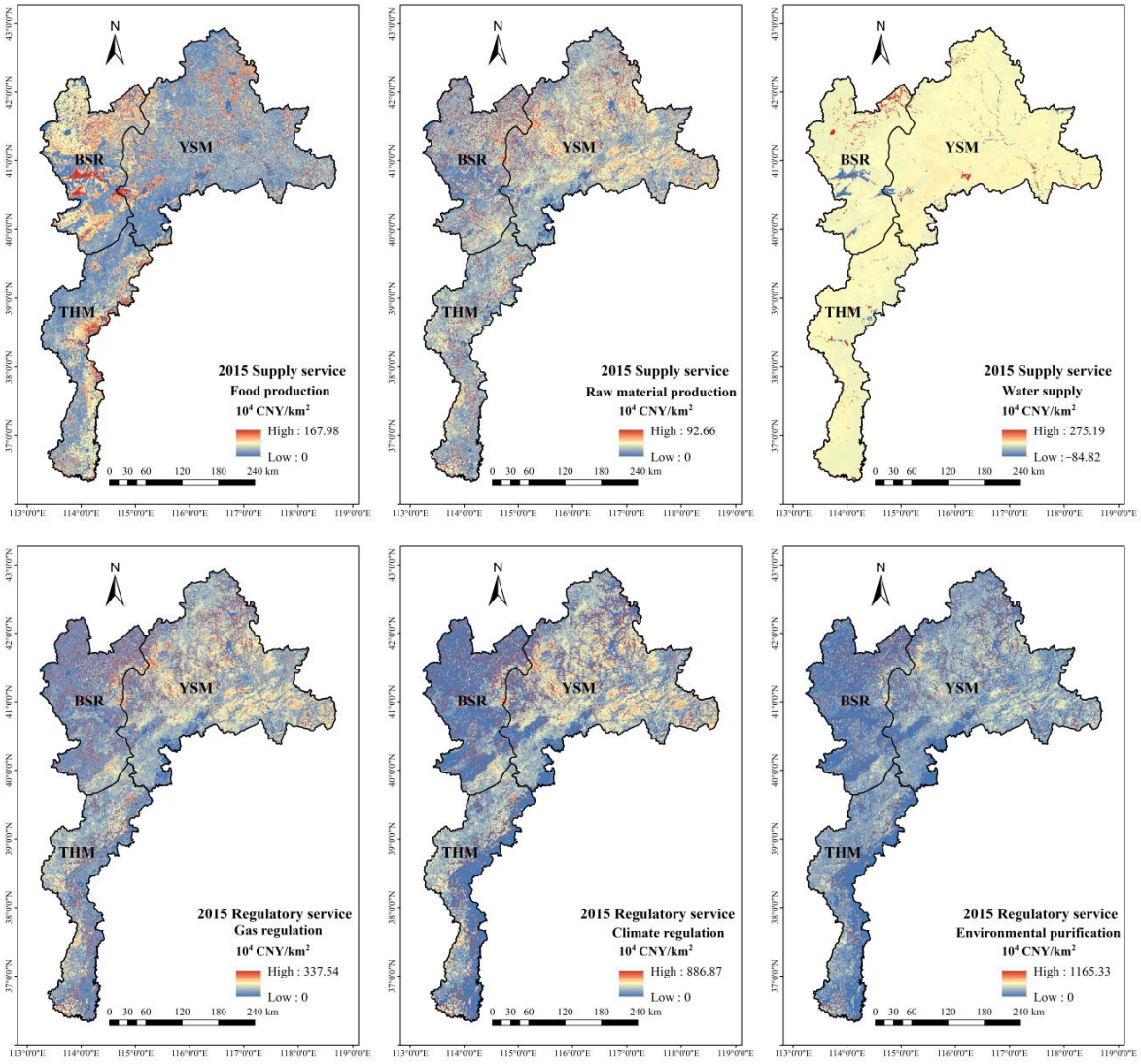


Figure 2. *Cont.*

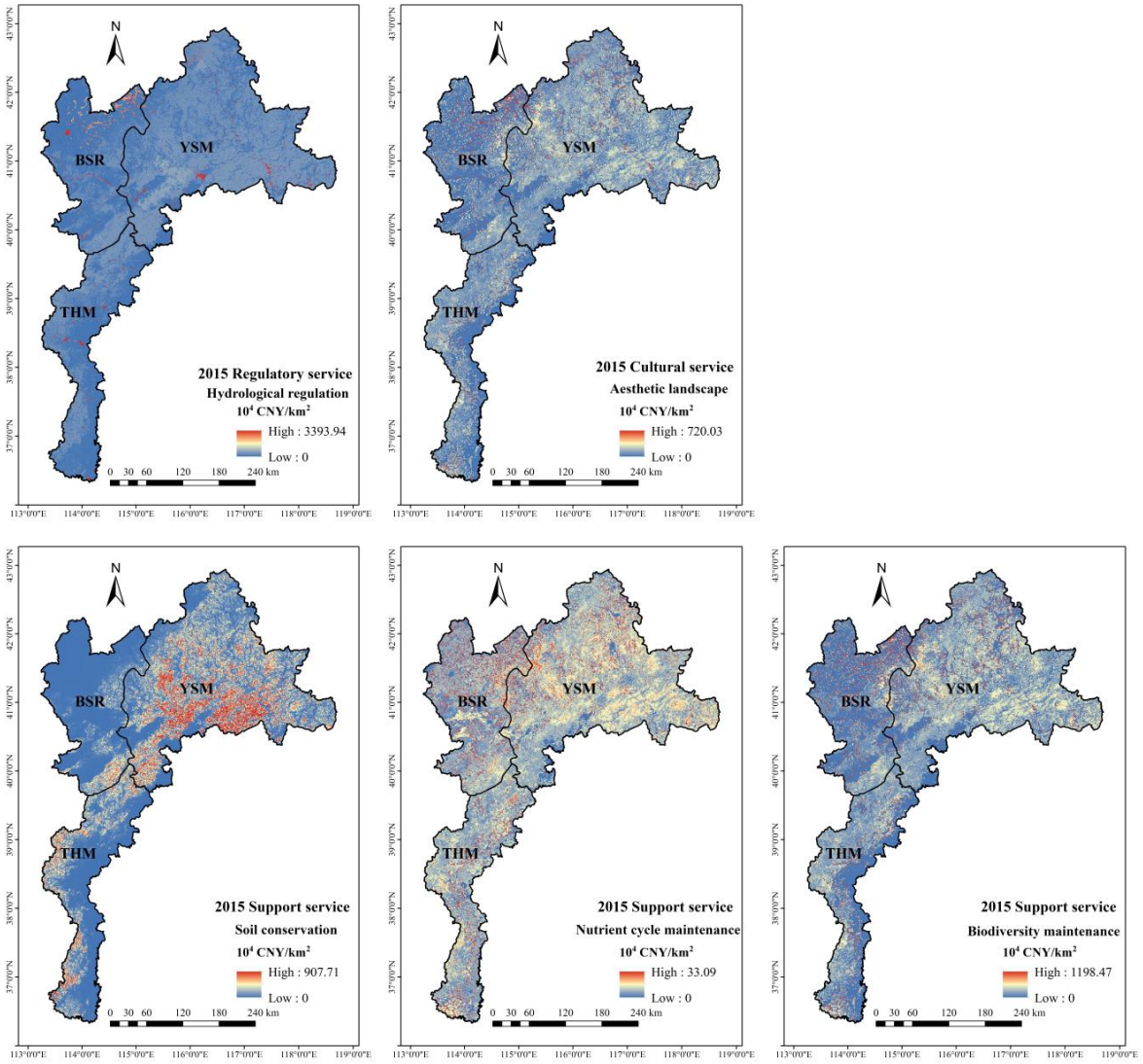


Figure 2. The spatial distribution of ESs in the study area in 2015.

Gas regulation, climate regulation, environmental purification, soil conservation, biodiversity maintenance and aesthetic landscape services showed the same spatial distribution. The higher value was clumped within the northeastern, namely, the YSM and higher elevation in the southwestern areas, namely, the west of the THM and the lower value was mainly concentrated in the northwestern, namely, the BSR, and southeastern mountain–plain junction areas, namely, the east of the THM. Meanwhile, food production service also showed the same spatial distribution as those six ESs, only the high and low values were distributed in opposite areas, that is, the higher value was in the BSR and the east of the THM and the lower value was in the YSM and the west of the THM. Raw material production, water supply, hydrological regulation and nutrient cycle maintenance services showed little spatial difference, especially, the water supply and nutrient cycle maintenance services, the values were mainly concentrated in the range of 0–10 $\times$ 10^4 CNY/km^2, accounting for 89.61% and 91.47% of the study area, respectively.

3.2. Correlation Analysis of ESs

The Spearman's correlation coefficients of the eleven ESs in 2015 at different spatial levels, including 1 km $\times$ 1 km grid scale, township scale, county scale and land use type scale were calculated. Land use types include farmland, woodland, grassland, water body, construction land and bare land. We obtained fifty-five pairs of services with trade-offs

and synergistic relationships. There were twenty-three pairs of ESs that were significantly correlated (Table 3) at all four scales and all were synergistic (Figure 3). Moreover, for other twenty-two pairs of ESs, the relationships between did not pass the significance test at land use type scale, therefore, we only plotted ES relationships at grid, township and county scales (Figure 4). In Figures 3 and 4, different color and thickness of lines denoted the different degrees of trade-offs and synergistic relationships between ESs, respectively. And the R values were divided into four intervals, representing weak correlation ($|R| < 0.4$), medium correlation ($0.4 < |R| < 0.6$), strong correlation ($0.6 < |R| < 0.8$) and very strong correlation ($|R| > 0.8$), respectively.

As shown in Figure 3, only five pairs of ESs showed extremely strong synergistic correlations at four scales, whose correlation coefficients R values were greater than 0.8, including raw material production service and nutrient cycle maintenance service, water supply service and hydrological regulation service, environmental purification service and biodiversity maintenance service, environmental purification service and aesthetic landscape service, and biodiversity maintenance service and aesthetic landscape service.

For those twenty-three pairs of services, the correlation coefficients R values at the land use type scale were all greater than 0.8, while there was no correlation between food supply service and other services (Figure 3). Compared with other three scales, R values between ESs were relatively low, many were less than 0.6 and below. And R values at the grid and township scales reflected a more similar distribution.

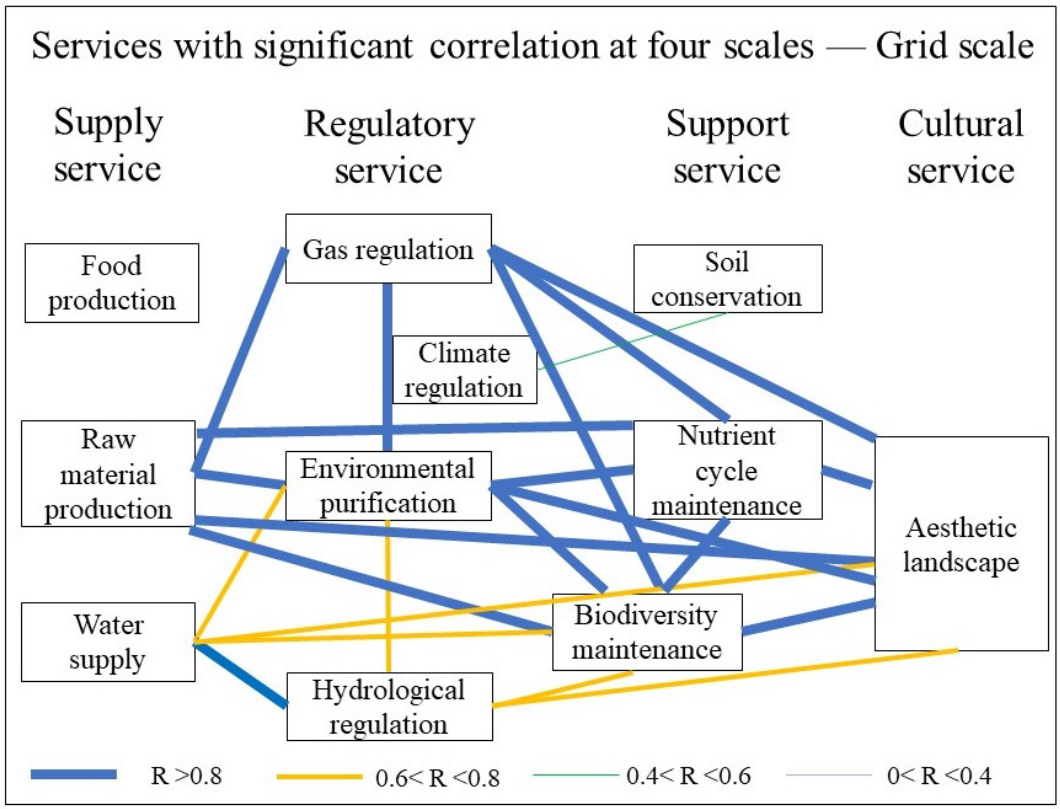
As shown in Figure 4, for these twenty-two pairs of ESs, different scales showed different synergies and trade-offs. In general, the correlations among individual services were relatively similar at the township and county scales, with food production service showing trade-offs with all six services except for nutrient cycling maintenance service. In addition, the negative correlations between food production service and water supply service, hydrological regulation and soil conservation services increased with the increasing scale. Except for food production service, the relationships between climate regulation service and other ESs were all synergies and the positive correlations were relatively large at those three scales. In addition, we can see that the synergistic relationship correlations between biodiversity maintenance and aesthetic landscape services and other 9 ESs were stronger at all four scales.

As for the remaining ten pairs of ESs, nine pairs of ESs showed different degrees of synergistic relationships at the grid and township scales, and food production service and gas regulation service only showed weakly correlated synergistic relationships at the grid scale.

Table 3. R and I value among six major ESs at different scales in the study area in 2015 (CR—climate regulation, HR—hydrological regulation, GR—gas regulation, EP—environmental purification, SC—soil conservation, and BM—biodiversity maintenance).

Service Pair	*R/I*				Service Pair	*R/I*			
	Grid	Township	County	Land Use		Grid	Township	County	Land Use
CR-HR	0.630 **/0.002	0.495 **/0.086	0.442 **/0.330	0.486 #/0.212	HR-BM	0.630 **/0.037	0.544 **/0.065	0.427 **/0.259	0.829 */0.394
CR-GR	0.979 **/0.200	0.949 **/0.251	0.199 #/0.374	0.486 #/0.962	GR-EP	0.972 **/0.132	0.872 **/0.228	0.253 ##/0.403	0.943 **/0.750
CR-EP	0.985 **/0.138	0.891 **/0.240	0.954 **/0.441	0.429 **/0.683	GR-SC	0.358 **/0.120	0.635 **/0.182	0.037 #/0.278	0.143 #/0.578
CR-SC	0.400 **/0.190	0.793 **/0.277	0.779 **/0.414	0.829 */0.735	GR-BM	0.976 **/0.084	0.940 **/0.238	0.255 ##/0.384	0.943 **/0.206
CR-BM	0.990 **/0.151	0.953 **/0.253	0.945 **/0.383	0.429 #/0.611	EP-SC	0.378 **/0.084	0.642 **/0.238	0.665 **/0.384	0.029 #/0.206
HR-GR	0.560 **/−0.010	0.393 **/0.041	0.171 #/0.225	0.657 #/0.237	EP-BM	0.997 **/0.137	0.945 **/0.237	0.977 **/0.429	0.999 **/0.854
HR-EP	0.625 **/0.066	0.661 **/0.070	0.530 **/0.323	0.829 */0.765	SC-BM	0.379 **/0.090	0.704 **/0.229	0.663 **/0.274	0.029 #/0.227
HR-SC	0.559 **/0.029	0.572 **/0.155	0.589 **/0.495	−0.029 #/−0.139					

#: $p > 0.1$, ## $0.05 < p < 0.1$, * $0.01 < p < 0.05$, and ** $p < 0.01$.



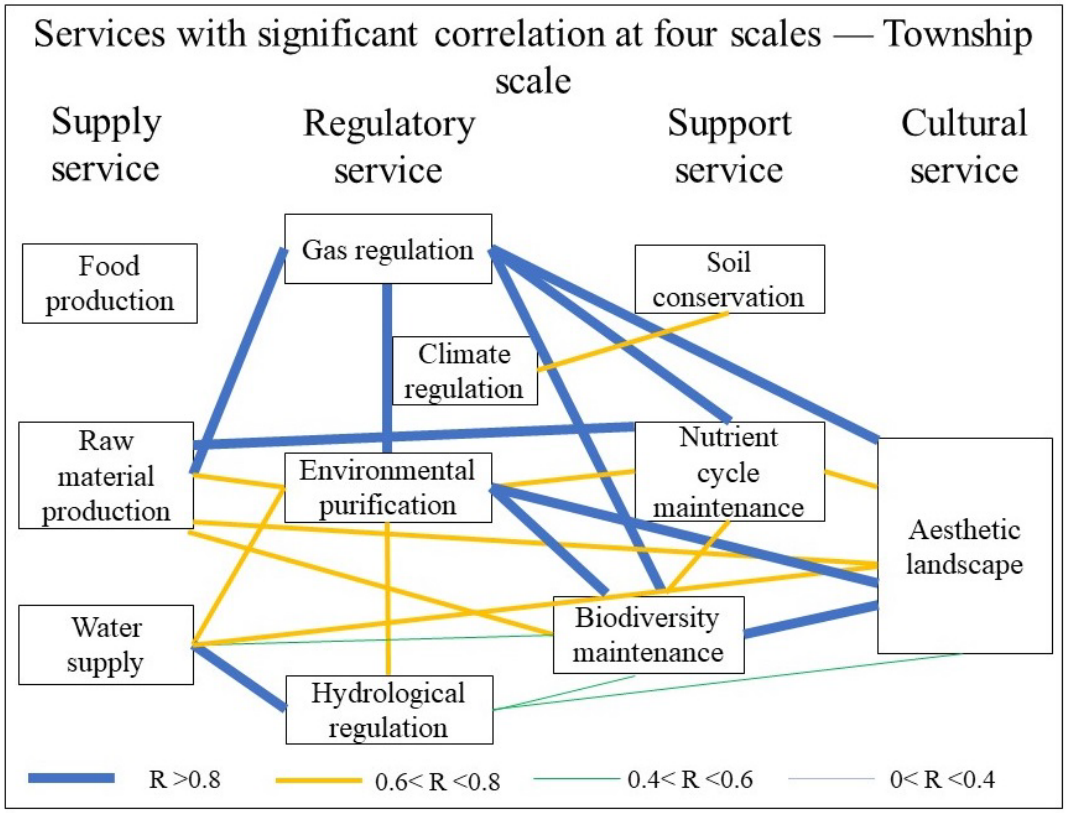


Figure 3. *Cont.*

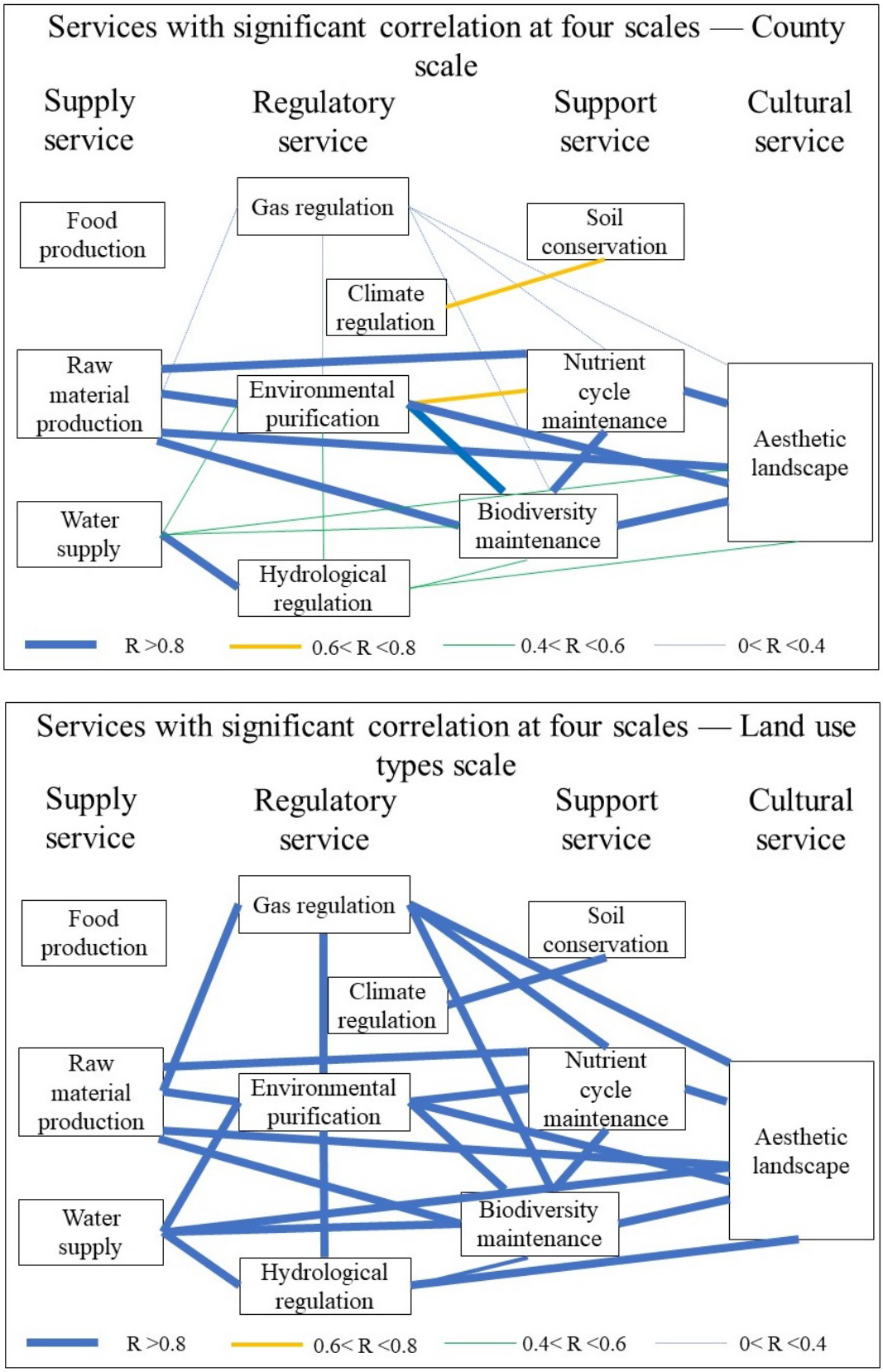
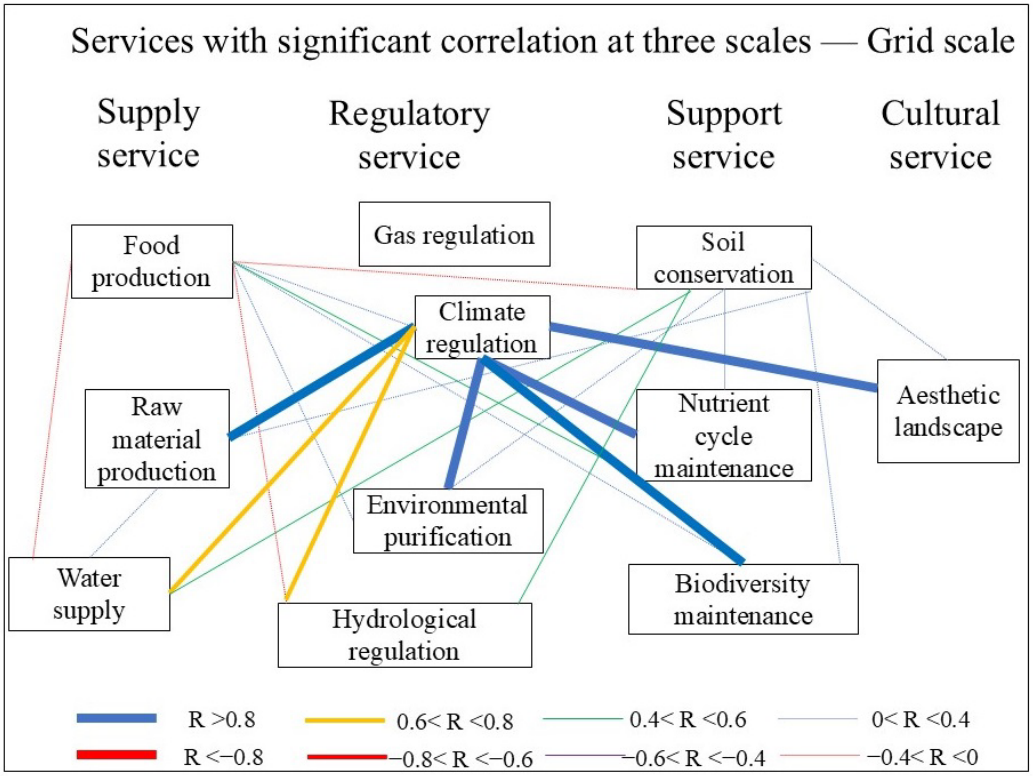


Figure 3. Services with significant correlation at four scales.



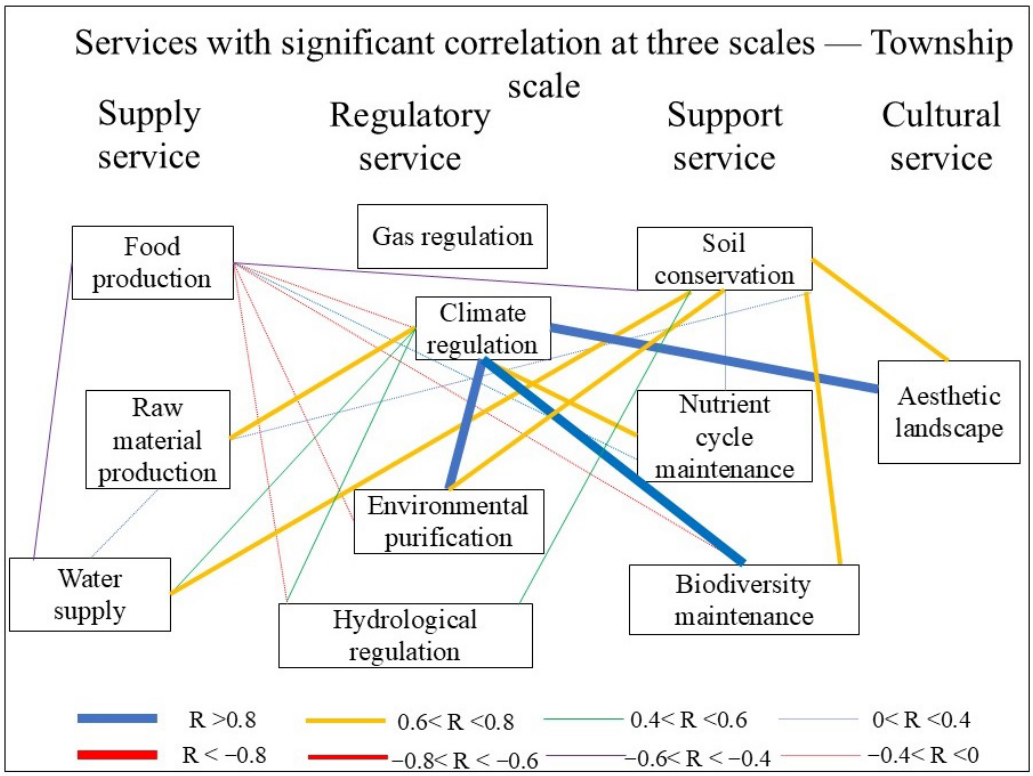


Figure 4. *Cont.*

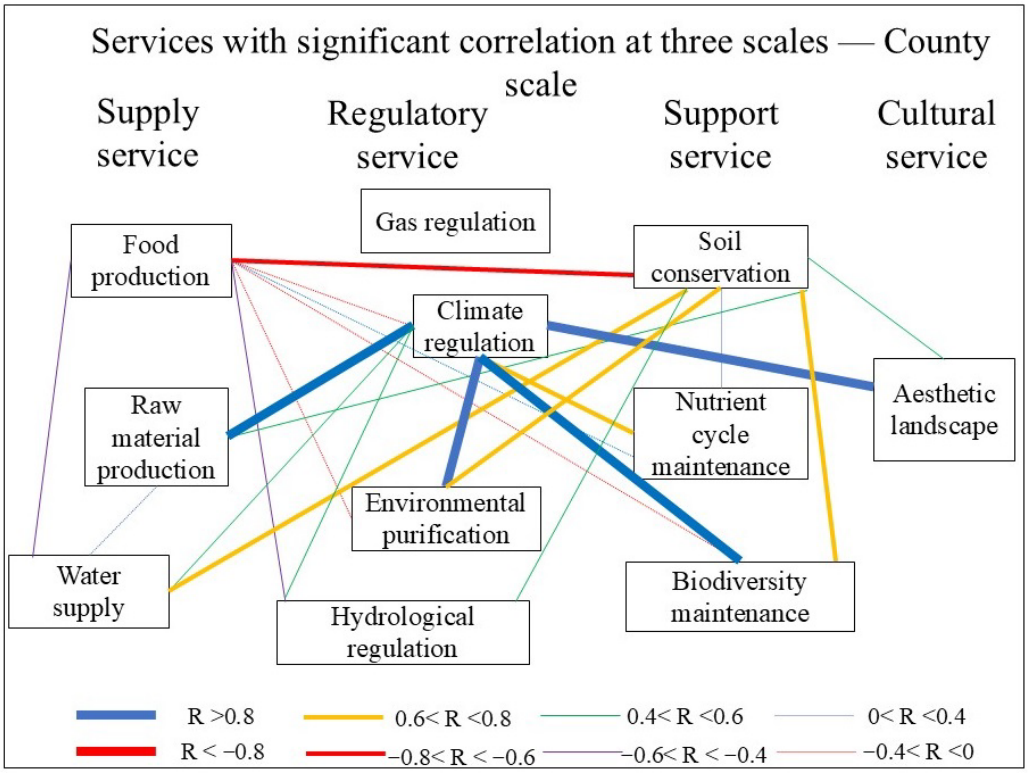


Figure 4. Services with significant correlation at three scales.

3.3. Spatial Trade-Offs/Synergies of ESs

As mentioned above, there were twenty-three pairs of services that were significantly correlated at all four scales, including ten ES categories except for food production service. Meanwhile, according to Section 3.1, in the study area, regulation service value was the highest, climate regulation service value and hydrological regulation service value accounted for 25.19% and 17.65% of the total value in 2015, respectively, followed by gas regulation service value (10.13%) and environmental purification service value (8.36%). Support service value ranked the second of the four ES primary categories, soil conservation service value and biodiversity maintenance service value accounted for 14.78% and 10.43% of the total value in 2015, respectively. Therefore, we analyzed the spatial trade-offs/synergies of those six major ESs at the different spatial scales in 2015. Similarity, I was divided into four intervals, representing weak correlation ($|I| < 0.4$), medium correlation ($0.4 < |I| < 0.6$), strong correlation ($0.6 < |I| < 0.8$) and very strong correlation ($|I| > 0.8$), respectively. The R and I value among ESs at different scales were shown in Table 3.

As shown in Table 3, the spatial autocorrelation among services at different scales was basically consistent with the statistical correlation, but the degree of correlation varied, especially at the grid scale, where the degree of spatial autocorrelation among services was weaker. For the township and county scale, the I values were basically less than 0.4. However, the degree of spatial autocorrelation at land use type scale was basically the same as the degree of statistical correlation, which included the strong synergistic of CR-EP, CR-SC, HR-EP, GR-EP and EP-BM, passing the significance test at p value < 0.05 and below. Further, we obtained the cluster maps among six major ESs at different scales (Figures 5–8). Clusters were identified by integers specifying the type of spatial association: 0 for non-significant (the p value chosen for this paper so far was 0.05 and below), 1 for high–high, 2 for low–low, 3 for low–high, and 4 for high–low, namely, 1 and 2 for the synergistic relationships and 3 and 4 for the trade-off relationships.

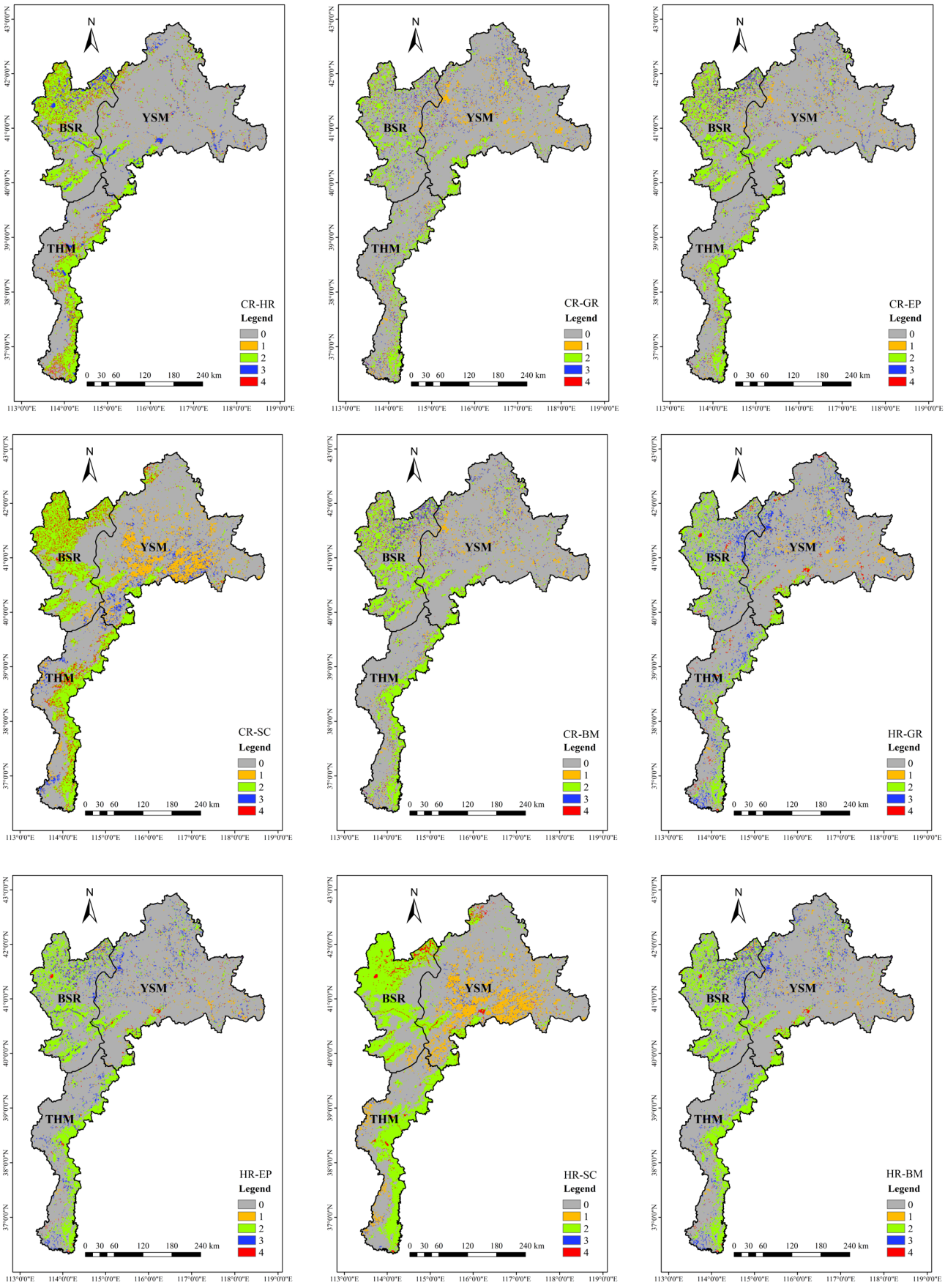


Figure 5. *Cont.*

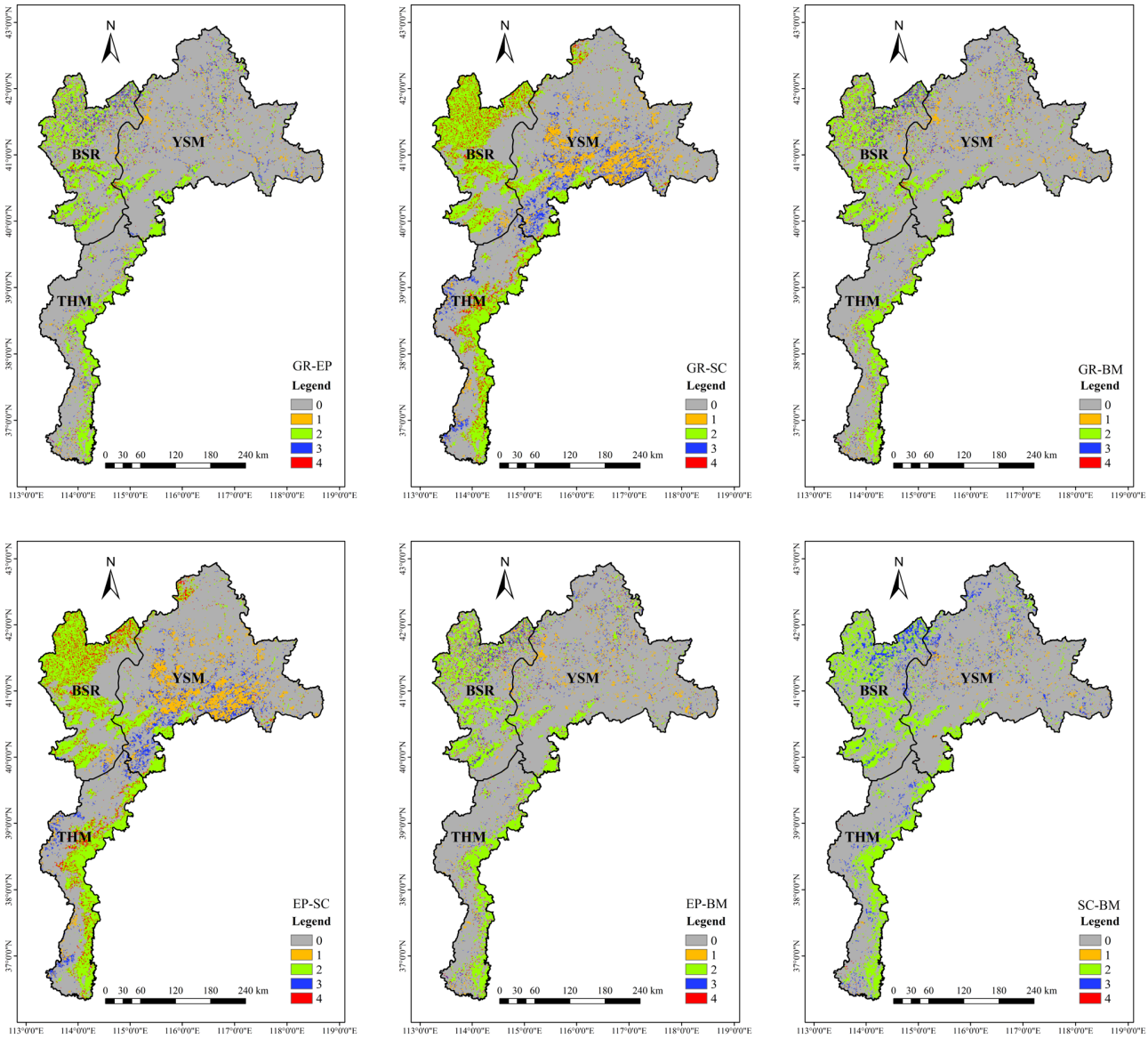


Figure 5. The cluster map among six major ESs at grid scale in the study area in 2015 (CR—climate regulation, HR—hydrological regulation, GR—gas regulation, EP—environmental purification, SC—soil conservation, and BM—biodiversity maintenance).

For grid scale, fifteen pairs of ESs showed the same spatial clustering characteristics: the synergy of low values distributed in the mountain–plain junction of the THM and in the northwestern BSR. CR-SC, HR-SC, GR-SC and EP-SC all showed synergy of high values in the central YSM and a trade-off of low and high values at the junction of YSM and THM, i.e., low values of CR, HR, GR and EP and high values of SC. The rest of the service pairs were basically not significantly correlated.

For township scale, the service pairs exhibited different spatial aggregation distribution characteristics. CR-HR had unique spatial autocorrelation distribution characteristics, with some townships in the mountainous area of the YSM bordering the plain being synergistic with high–high values, while some townships in the mountainous area of the THM bordering the plain and in the south of the THM had a low–low value synergistic and high–low value trade-off distribution. CR-GR, CR-EP, CR-BM, GR-EP, GR-BM, EP-BM and SC-BM also had the same spatial autocorrelation mainly in some townships of the YSM and THM. Specifically, CR-GR, CR-EP, CR-BM, GR-EP, GR-BM, EP-BM and SC-BM showed the high–high value synergistic distribution in the central townships of the YSM

and some townships on the border between the THM and BSR and northwest of the THM, and some townships in the mountain–plain junction of southwest the YSM and THM were interspersed with the trade-off relationship of high and low values and the synergistic relationship of low and low values, while some townships in the northwest of the YSM and THM, HR-GR, HR-EP, HR-BM turned out to be a trade-off distribution of low and high values. In the south-central townships of the BSR, only CR-SC, HR-SC, GR-SC and EP-SC showed an alternating distribution of low–low value synergies and high–low value trade-offs, and those four services pairs showed the same spatial autocorrelation characteristics and distribution area in the YSM and THM as the seven pairs of services such as CR-GR.

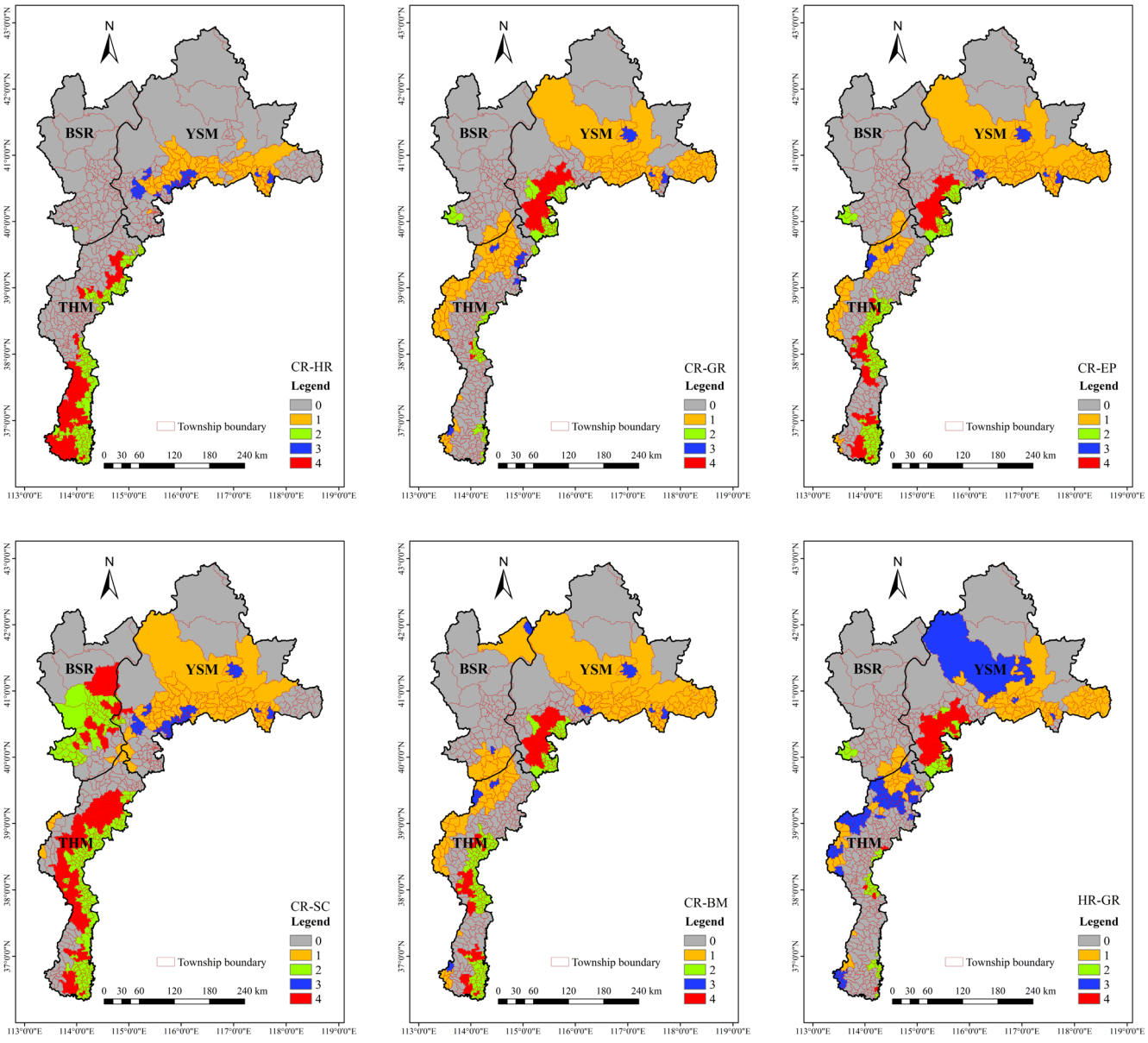


Figure 6. *Cont.*

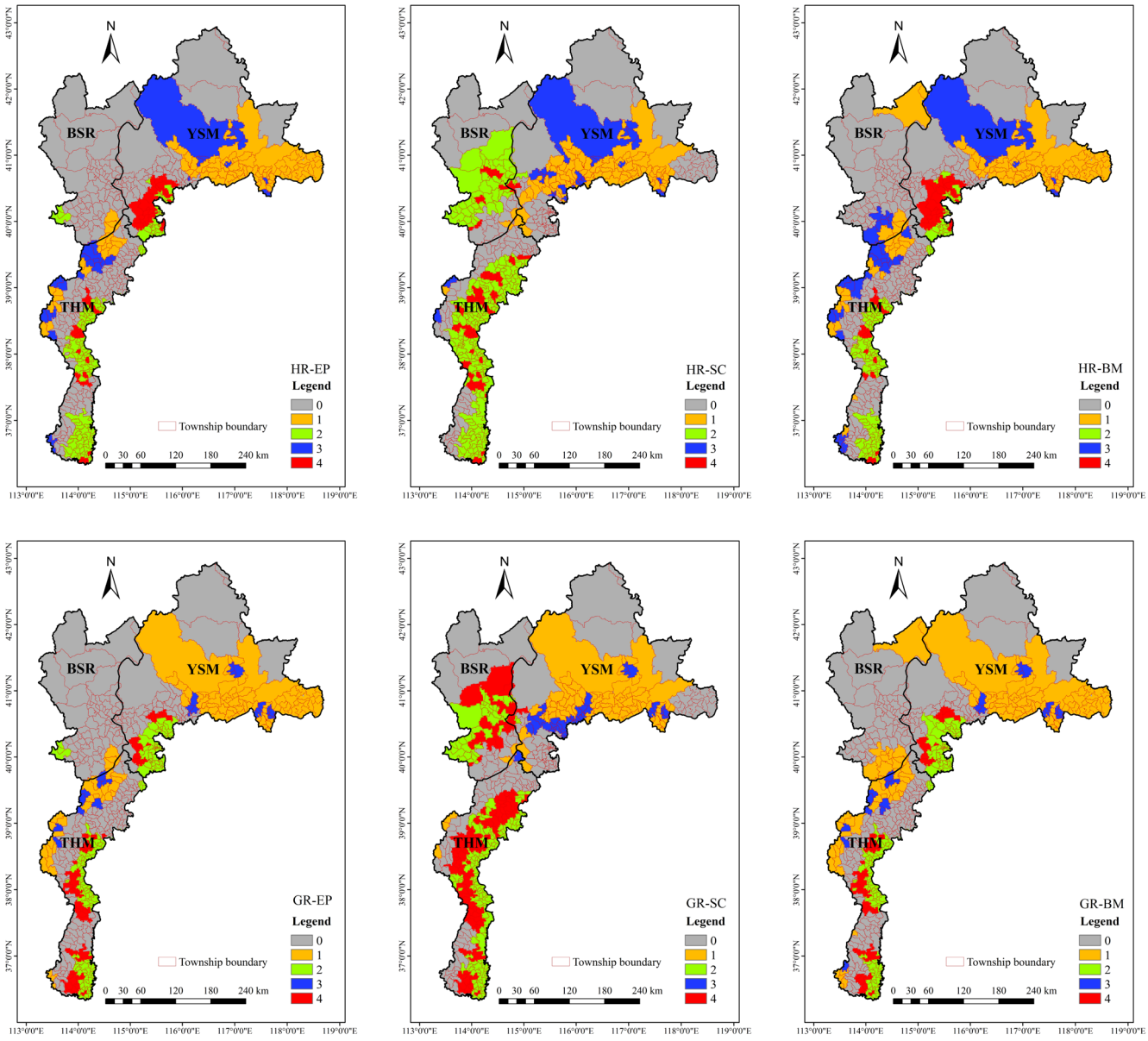


Figure 6. *Cont.*

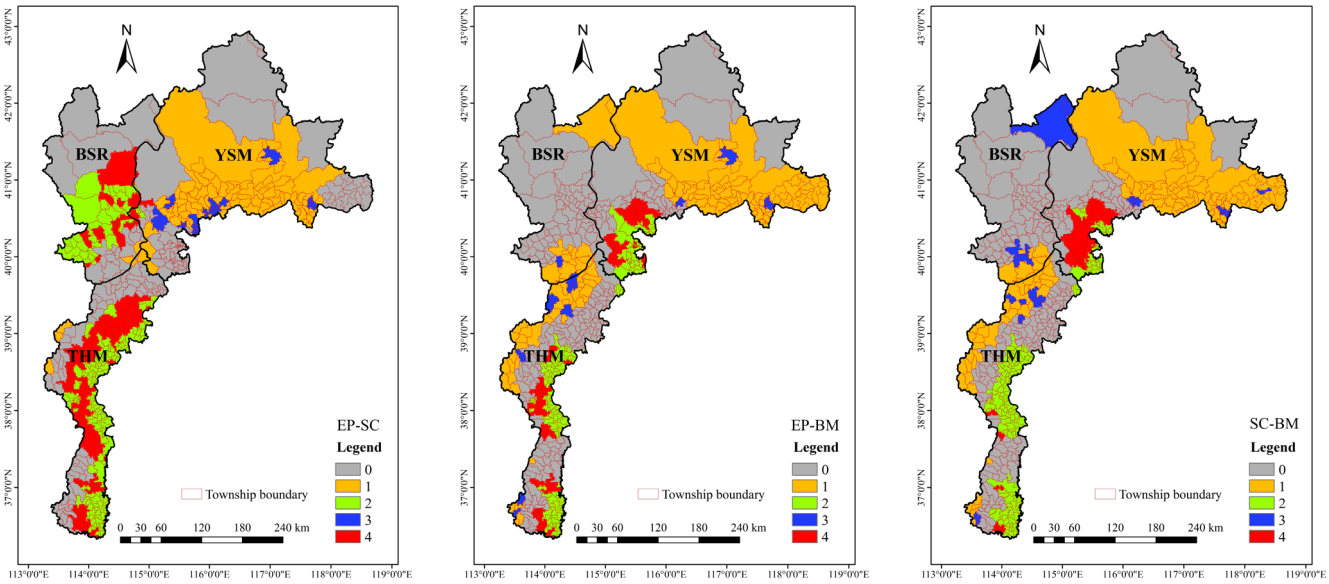


Figure 6. The cluster map among six major ESs at township scale in the study area in 2015 (CR—climate regulation, HR—hydrological regulation, GR—gas regulation, EP—environmental purification, SC—soil conservation, and BM—biodiversity maintenance).

For county scale, in general, except for HR-GR, HR-EP, HR-BM and SC-BM in three to four counties located in the northwest of the YSM, which were low–high value trade-offs, other service pairs in some counties of the YSM were basically high–high value synergistic relationships. The other service pairs in some counties in the YSM were basically high–high value synergistic relationships, while both in the BSR and THM showed a staggered distribution of low–low value synergistic and high–low value trade-offs. Specifically, some counties in the THM, mainly in the south, had this spatial aggregation feature, while only about five counties in the central part of the BSR had this distribution feature in CR-SC, HR-SC, GR-SC and EP-SC. In the other counties of the study area, all service pairs had no spatial autocorrelation.

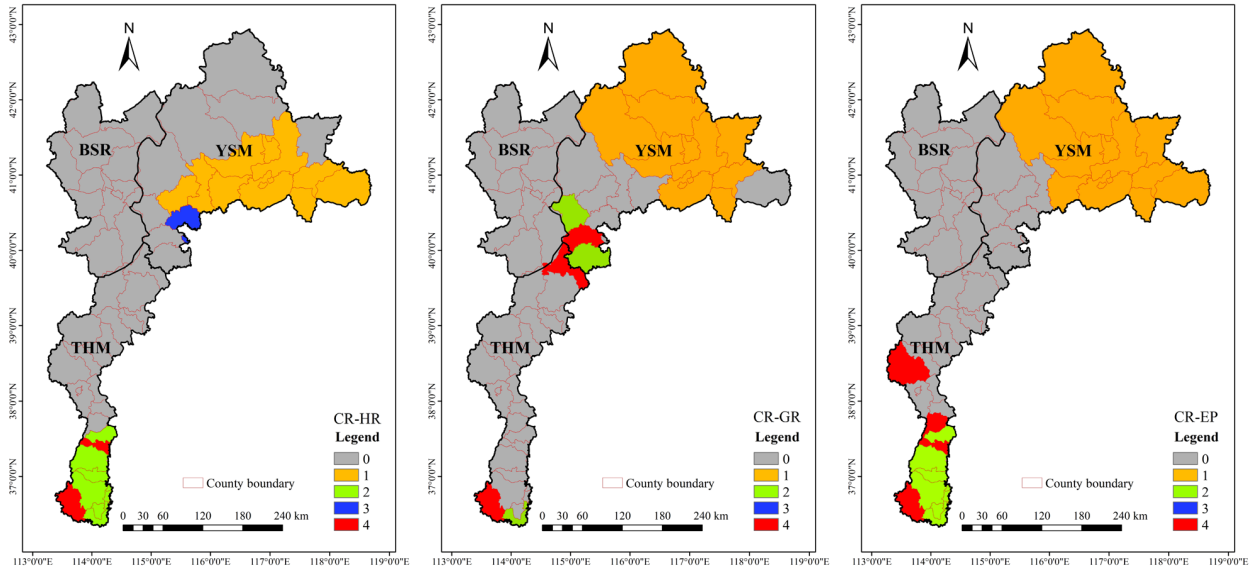


Figure 7. *Cont.*

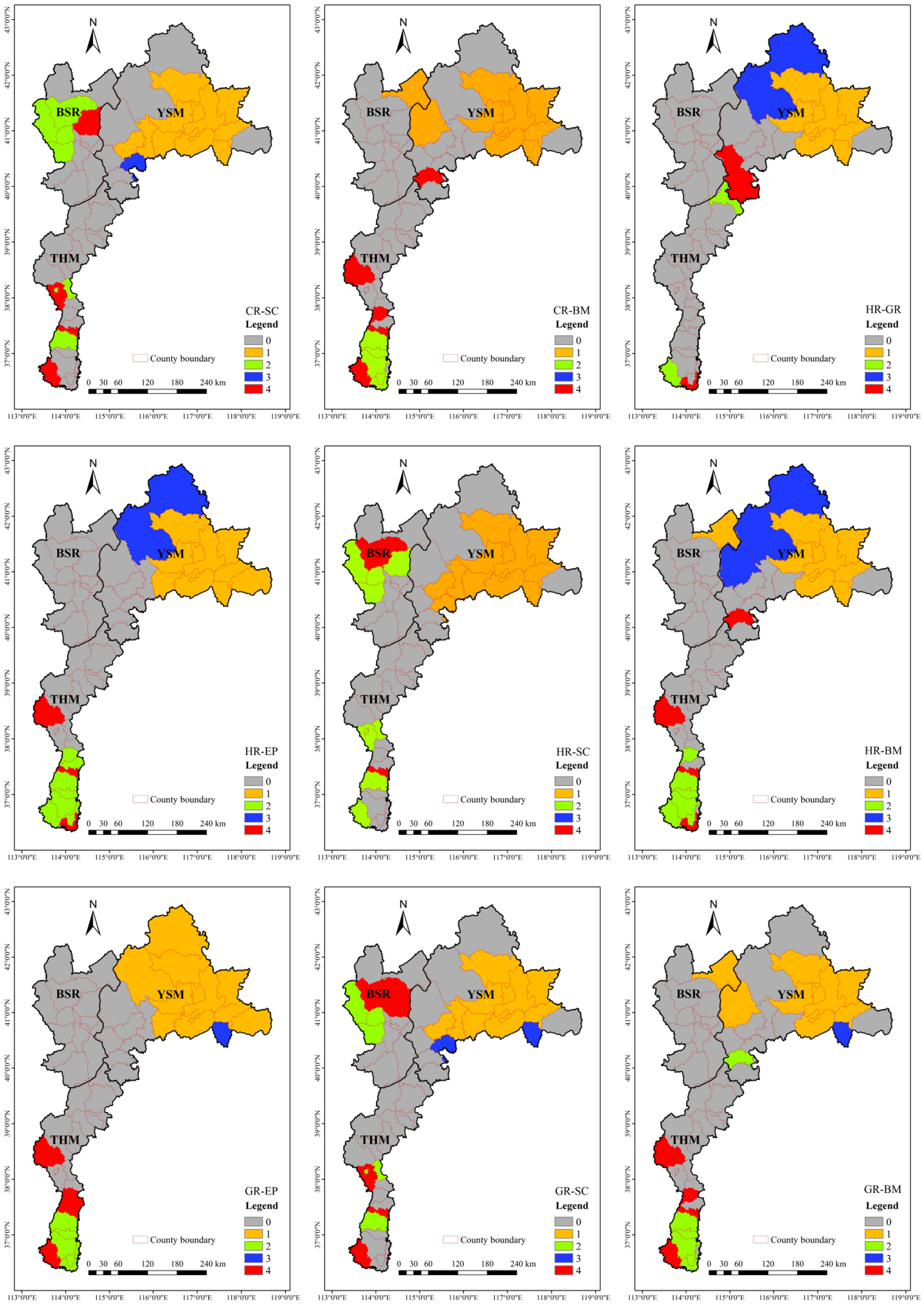


Figure 7. *Cont.*

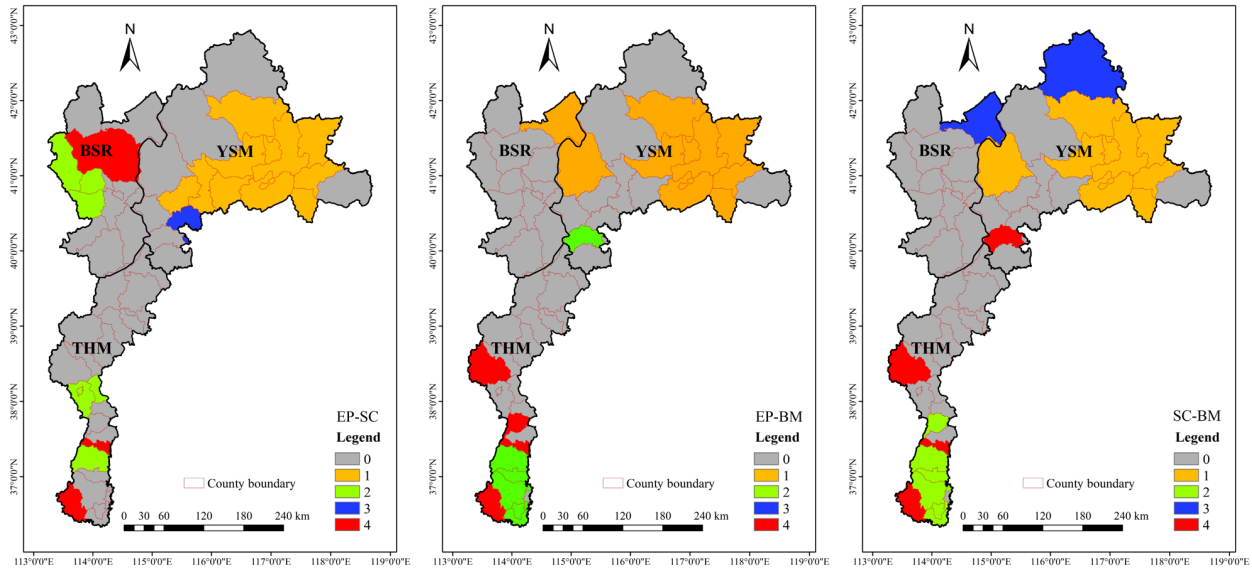


Figure 7. The cluster map among six major ESs at county scale in the study area in 2015 (CR—climate regulation, HR—hydrological regulation, GR—gas regulation, EP—environmental purification, SC—soil conservation, and BM—biodiversity maintenance).

Unlike the grid, township and county scales, the spatial clustering of each ES pair in the land use type scale was completely as the land use types were scattered in patches. The biggest difference was that all service pairs were spatially autocorrelated across the study area at the land use type scale and the clustering characteristics were more obvious and similar. All service pairs were synergistic with low–low values at the mountain–plain junction in the THM and in the northern part of the BSR, while different service pairs in other regions showed different correlations with each other. Specifically, in the YSM, western THM and the junction between the BSR and THM, CR-HR was a trade-off between high and low values, HR-GR, HR-EP, HR-SC and HR-BM were trade-offs between low and high values, while all other service pairs were synergistic between high and high values.

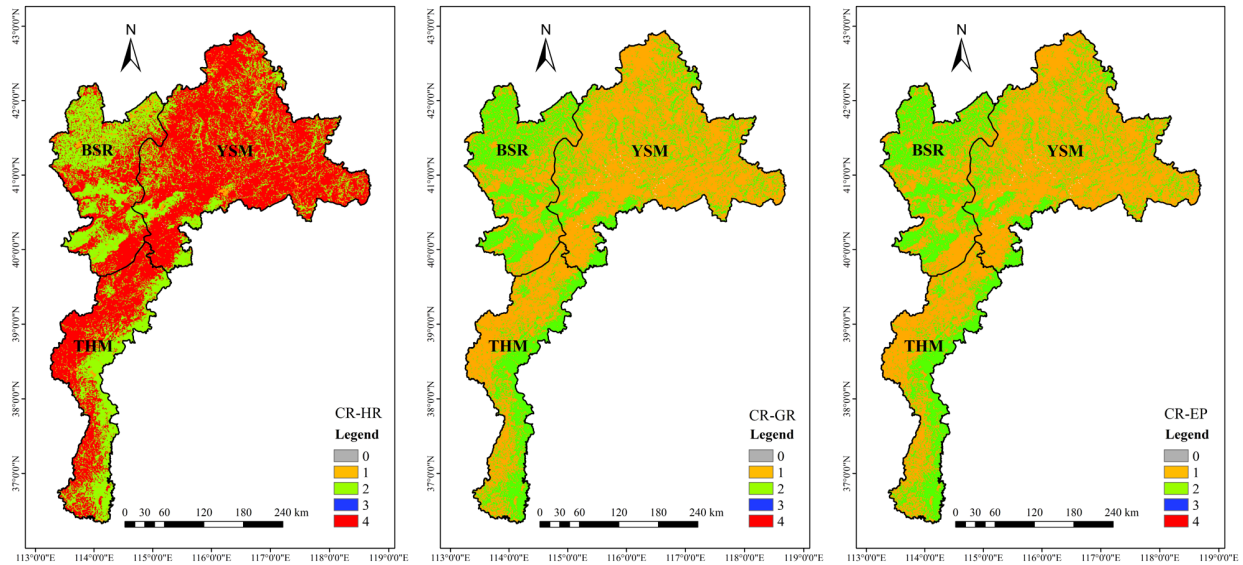


Figure 8. *Cont.*

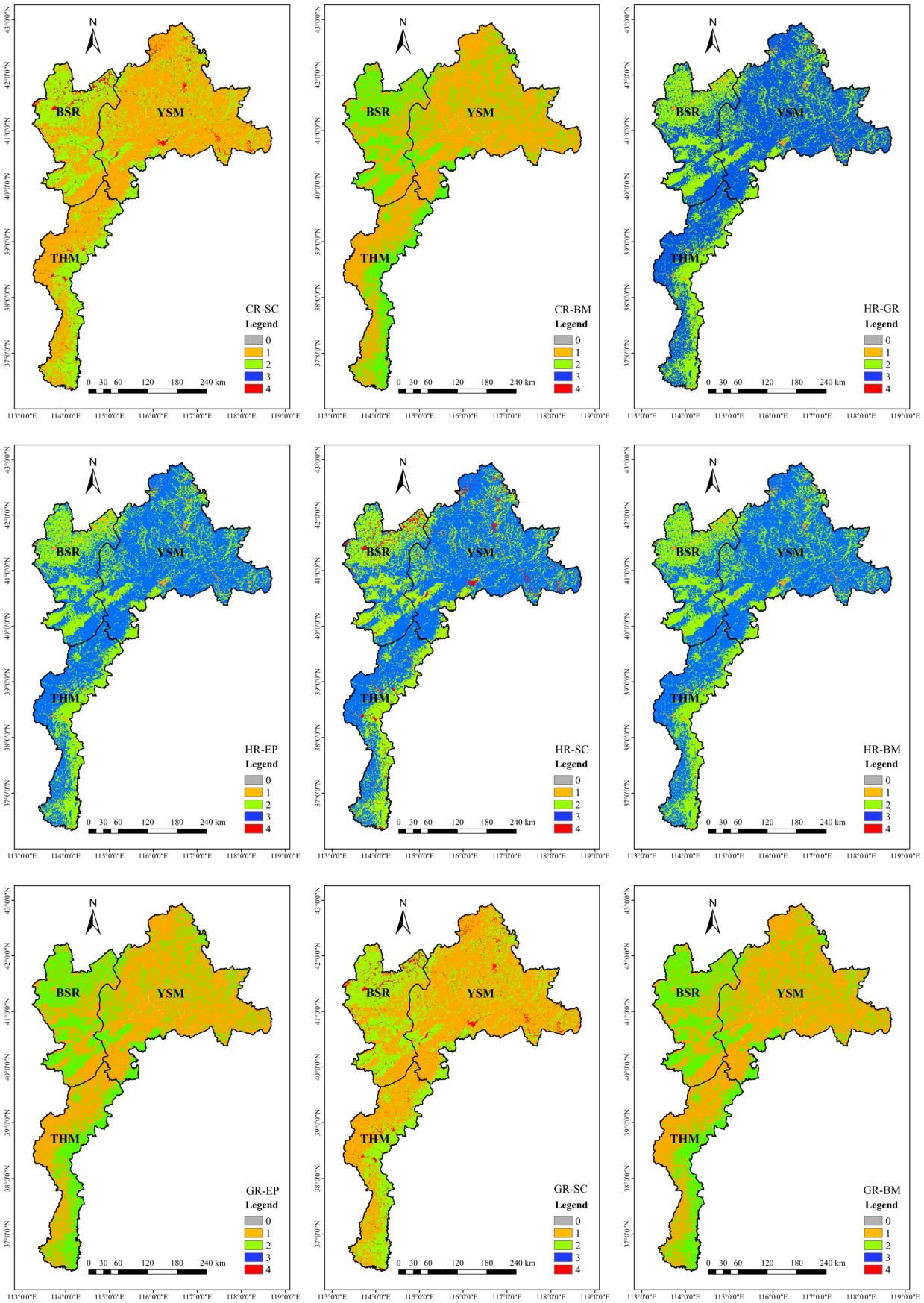


Figure 8. *Cont.*

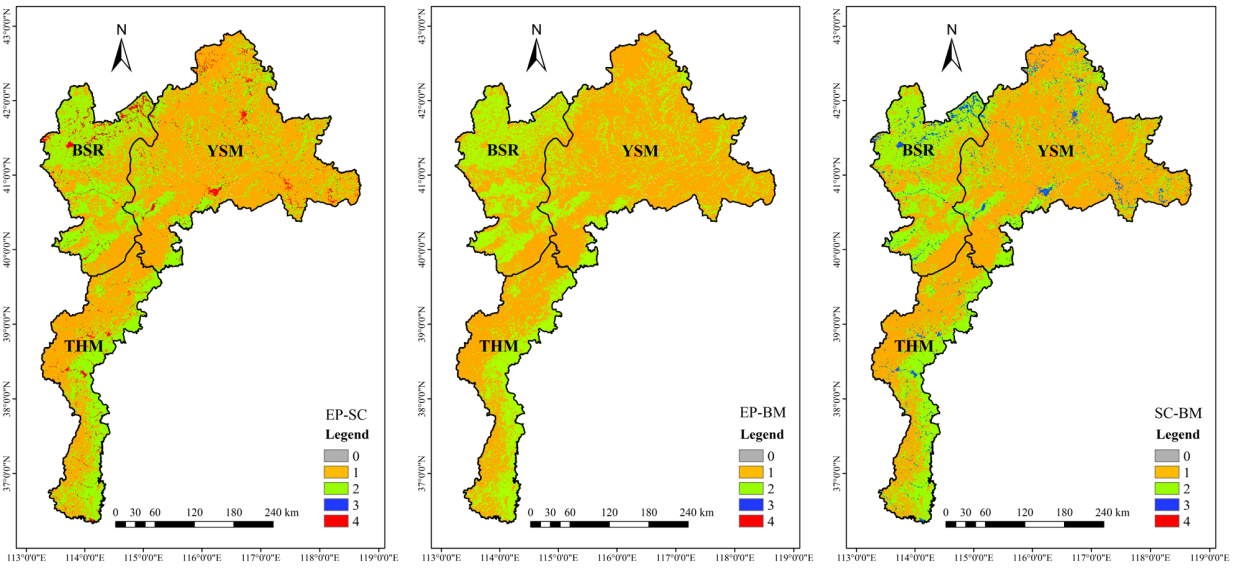


Figure 8. The cluster map among six major ESs at land use type scale in the study area in 2015 (CR—climate regulation, HR—hydrological regulation, GR—gas regulation, EP—environmental purification, SC—soil conservation, and BM—biodiversity maintenance).

4. Discussion

4.1. Scale Effect on Trade-Offs/Synergies of ESs

Scale refers to the extent or frequency of a geographic phenomenon or ecological processes under specific spatial and temporal conditions. It is very important in geographic and ecological studies [51]. The response of patterns or processes to spatial and temporal scales can be used to reveal the scale effects of natural phenomena [52]. Ecosystem function is derived from the interactions between landscape patterns (patch structure, corridor layout, landscape diversity, etc.) and ecological processes (regional soil and water processes or global climate change, etc.) and the scale constraints on these interactions [52]. Therefore, ESs also have a scale effect [8], and meanwhile, some research results show that trade-offs and synergies relationships of ESs have a certain scale effect as well [53,54].

In this paper, each service pair shows greater spatial autocorrelation at the land use type scale, while it shows less spatial autocorrelation at other scales, and the preliminary analysis suggests that the ESs studied in this paper are trade-offs and synergies between climate regulation, hydrological regulation, soil conservation, etc. These services are longer-term (monthly or quarterly) ecological regulation and maintenance services for all land use types (woodland, grassland, cropland, water, etc.) across the region. Unlike the food production service, which belongs to the short-cycle local (cropland) ecological provisioning service [8]. From this, we infer that the spatial trade-offs and synergies of regulating and maintenance services are closely related to the spatial distribution of land use types. As for the grid scale, township scale and county scale, since different land use types are distributed in patches, it may appear that the same area contains many different land use types, and the trade-offs and synergistic relationships of each service in different land use types cause their correlations to cancel each other out, and finally, the spatial correlations of these three scales are not significant. Thus, for effective decision making and management, both administrative and natural boundaries should be considered in order to optimize the value of ecosystem services. Of course, spatial and temporal differences in direct interactions or common drivers among services may also lead to changes in the trade-offs and synergistic relationships among ESs [55]. This includes internal ecosystem factors and socioeconomic factors. Therefore, further analysis of the influence of spatial differences in each socioecological factor on the ES relationships is needed.

4.2. Driving Factors on Spatial Trade-Offs/Synergies of ESs

In this paper, the driving factors on spatial trade-offs/synergies of ESs in the study area include natural factors and socioeconomic factors. Natural factors consist of the climate factors, including precipitation and ET_0, soil property, expressed by soil organic carbon fraction, vegetation factor, reflected by NDVI change, and topographic conditions, in terms of elevation, slope and aspect. Socioeconomic factors contain land use intensity, population density, economic density and GDP per capita. Since socioeconomic factors are counted by administrative districts, we only analyze the reasons for spatial differences in ESs trade-offs and synergies at the township (Table 4).

Table 4. Correlation coefficients between factors and cluster values among six major ESs at the township scale in the study area in 2015 (CR—climate regulation, HR—hydrological regulation, GR—gas regulation, EP—environmental purification, SC—soil conservation, and BM—biodiversity maintenance).

Service Pair	Precipitation	ET_0	Soil Organic Carbon	NDVI	Elevation	Slope	Aspect	Land Use Intensity	Population Density	GDP per Capita	Economic Density
CR-HR	−0.131 **	0.031	−0.145 **	−0.057	−0.323 **	−0.116 **	−0.232 **	0.134 **	0.257 **	0.099 *	0.248 **
CR-GR	0.397 **	0.214 **	−0.223 **	0.108 *	−0.151 **	0.077	−0.042	−0.045	0.146 **	0.212 **	0.194 **
CR-EP	0.054	0.012	−0.166 **	−0.049	−0.304 **	−0.082	−0.137 **	0.128 **	0.398 **	0.269 **	0.416 **
CR-SC	−0.265 **	−0.119 **	0.068	−0.251 **	−0.188 **	−0.200 **	−0.088 *	0.143 **	0.207 **	−0.201 **	0.111 **
CR-BM	0.103 *	0.003	−0.195 *	−0.017	0.275 **	−0.072	−0.083	0.116 **	0.366 **	0.253 **	0.382 **
HR-GR	0.368 **	0.184 **	−0.193 **	0.144 **	−0.103 *	0.132 **	−0.008	−0.103 *	0.097 *	0.171 **	0.137 **
HR-EP	0.089 *	0.02	−0.178 **	−0.009	−0.282 **	−0.052	0.120 **	0.095 *	0.357 **	0.261 **	0.380 **
HR-SC	−0.276 **	−0.111 **	0.032	−0.244 **	−0.221 **	−0.330 **	−0.139 **	0.251 **	0.209 **	0.197 **	0.139 **
HR-BM	0.120 **	−0.008	−0.174 **	0.036	0.217 **	−0.015	−0.045	0.073	0.311 **	0.207 **	0.311 **
GR-EP	0.029	−0.008	−0.153 **	−0.043	−0.292 **	−0.088 *	−0.122 **	0.117 **	0.364 **	0.250 **	0.390 **
GR-SC	−0.246 **	−0.109 *	0.058	−0.224 **	−0.186 **	−0.229 **	−0.078	0.153 **	0.201 **	−0.185 **	0.118 **
GR-BM	0.090 *	−0.009	−0.190 **	−0.004	−0.272 **	−0.065	−0.078	0.090 *	0.350 **	0.240 **	0.370 **
EP-SC	−0.293 **	−0.136 **	0.090 *	−0.266 **	−0.178 **	−0.241 **	−0.118 **	0.171 **	0.196 **	−0.216 **	0.106 *
EP-BM	0.086 *	−0.013	−0.175 **	−0.025	−0.265 **	−0.069	−0.093 *	0.120 **	0.362 **	0.234 **	0.370 **
SC-BM	0.155 **	0.017	−0.200 **	−0.017	−0.288 **	−0.077	−0.08	0.127 **	0.372 **	0.256 **	0.390 **

** Significantly correlated at $p < 0.01$; * Significantly correlated at $p < 0.05$.

As can be seen from Table 4, precipitation and ET_0 mainly negatively affected soil maintenance with all kinds of the regulating service. The effects of soil organic carbon on each service pair were also mainly negatively correlated, while land use intensity was mainly positively correlated. In comparison, the effects of NDVI, slope and aspect were not very significant in general. All service pairs were significantly correlated with the elevation, population density, GDP per capita, and economic density. Except for CR-BM and HR-BM, all service pairs were negatively correlated with elevation, except for CR-SC, GR-SC and EP-SC, all service pairs were positively correlated with GDP per capita, and all service pairs were positively correlated with economic density, which also indicated that the value of ESs was feasible as a green GDP indicator to reflect the economic level of a place from the ecological perspective. At the same time, it can be argued that the main natural influence on the synergistic trade-offs of ESs at the township scale was elevation, while socioeconomics was mainly influenced by population and GDP.

4.3. Limitations of This Study

This study analyzed only the effect of a single factor on the pairing of different ecosystem values, different ecosystem service value pairs were influenced by different factors. In fact, the combination of different factors may be one of the reasons for the spatial variability of the trade-off/synergy relationship, which is a limitation of this paper and will be a key issue in the next study. Meanwhile, the correlation analysis only characterized the numerical relationship between trade-offs and synergies of ecosystem services, but could not reveal the threshold characteristics of ecosystem service interactions. Therefore, an in-depth study of the threshold effects of trade-offs and synergies in the context of ecosystem service mechanisms may be an important aspect of the next step.

5. Conclusions

Understanding ecosystem service trade-offs and synergies is the foundation for achieving the efficient management of the ecosystem and improving human well-being. For the spatial pattern of ESs in the study area, the higher values of gas regulation, climate regulation, environmental purification, soil conservation, biodiversity maintenance and aesthetic landscape services were in the YSM and the west of the THM and the lower value was mainly concentrated in the BSR, and the east of the THM. And the higher value of food production service was in the BSR and the east of the THM and the lower value was in the YSM and the west of the THM. Raw material production, water supply, hydrological regulation and nutrient cycle maintenance services showed little spatial difference.

For the correlated relationship of ESs at four different spatial scales, only the raw material production service and nutrient cycle maintenance service, water supply service and hydrological regulation service, environmental purification service and biodiversity maintenance service, environmental purification service and aesthetic landscape service, and biodiversity maintenance service and aesthetic landscape service showed extremely strong synergistic correlations.

Unlike the grid, township and county scales, all service pairs were spatially autocorrelated across the study area at the land use type scale and the clustering characteristics were more obvious and similar. All service pairs were synergistic with low–low values at the mountain–plain junction in the THM and in the northern part of the BSR. In the YSM, western THM and the junction between the BSR and THM, CR-HR was a trade-off between high and low values, HR-GR, HR-EP, HR-SC and HR-BM were trade-offs between low and high values, while all other service pairs were synergistic between high and high values. The spatial trade-offs and synergies of the regulating and maintenance services in the study area were closely related to the spatial distribution of land use types.

At the township scale, precipitation and ET_0 mainly negatively affected soil maintenance with all kinds of the regulating service. The effects of soil organic carbon on each service pair were also mainly negatively correlated, while land use intensity was mainly positively correlated. Except for CR-BM and HR-BM, all service pairs were negatively correlated with elevation, except for CR-SC, GR-SC and EP-SC, all service pairs were positively correlated with GDP per capita, and all service pairs were positively correlated with economic density. The main natural influence on the synergistic trade-offs of ESs at the township scale was elevation, while socioeconomics was mainly influenced by population and GDP.

Author Contributions: Writing—original draft preparation, Xianglong Hou; writing—review and editing, Hui Yang; conceptualization, Jiansheng Cao. All authors have read and agreed to the published version of this manuscript.

Funding: This research was funded by the Science & Technology Fundamental Resources Investigation Program (grant number 2022FY100104), the National Natural Science Foundation of China (42371048), the Natural Science Foundation of Hebei Province (grant number D2021503001), the Key Research and Development Plan Project of Hebei Province (grant number 22324202D), the Science and Technology Program of Hebei Academy of Sciences (23104, 24104) and the Hebei Academy of Sciences High-level Talent Cultivation and Sponsorship Program (2023G01).

Data Availability Statement: All data, models, and code generated or used during this study appear in the submitted article.

Conflicts of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Synthesis*; Island Press: Washington, DC, USA, 2005.
2. Li, S.C.; Liu, M.J.L.; Zhang, C.Y.; Zhao, Z.Q. The research trends of ecosystem services and the paradigm in geography. *Acta Geogr. Sin.* **2011**, *66*, 1618–1630.

3. Zhao, W.W.; Liu, Y.; Feng, Q.; Wang, Y.P.; Yang, S.Q. Ecosystem services for coupled human and environment systems. *Prog. Geogr.* **2018**, *37*, 139–151.
4. Jiang, W.; Wu, T.; Fu, B.J. The value of ecosystem services in China: A systematic review for twenty years. *Ecosyst. Serv.* **2021**, *52*, 101365. [CrossRef]
5. Zheng, H.; Li, Y.F.; Ouyang, Z.Y.; Luo, Y.C. Progress and perspectives of ecosystem services management. *Acta Ecol. Sin.* **2013**, *33*, 702–710. [CrossRef]
6. Dai, E.F.; Wang, X.L.; Zhu, J.J.; Gao, J.B. Progress and Perspective on Ecosystem Services Trade-offs. *Adv. Earth Sci.* **2015**, *30*, 1250–1259.
7. Zanchi, G.; Brady, M.V. Evaluating the contribution of forest ecosystem services to societal welfare through linking dynamic ecosystem modelling with economic valuation. *Ecosyst. Serv.* **2019**, *39*, 101011. [CrossRef]
8. Li, S.C.; Zhhang, C.Y.; Liu, J.L.; Zhu, W.B.; Ma, C.; Wang, J. The tradeoffs and synergies of ecosystem services: Research progress, development trend, and themes of geography. *Geogr. Res.* **2013**, *32*, 1379–1390.
9. Dai, E.F.; Wang, X.L.; Zhu, J.J.; Zhao, D.S. Methods, tools and research framework of ecosystem service trade-offs. *Geogr. Res.* **2016**, *35*, 1005–1016.
10. Aziz, T. Changes in land use and ecosystem service values in Pakistan, 1950–2050. *Environ. Dev. Sustain.* **2021**, *37*, 100576. [CrossRef]
11. Wang, A.Y.; Liao, X.Y.; Tong, Z.J.; Du, W.L.; Zhang, J.Q.; Liu, X.P.; Liu, M.S. Spatial-temporal dynamic evaluation of the ecosystem service value from the perspective of "production-living-ecological" spaces: A case study in Dongliao River Basin, China. *J. Clean. Prod.* **2022**, *333*, 130218. [CrossRef]
12. Wang, P.T.; Zhang, L.W.; Li, Y.J.; Jiao, L.; Wang, H.; Yan, J.P.; Lv, Y.H.; Fu, B.J. Spatio-temporal characteristics of the trade-off and synergy relationships among multiple ecosystem services in the Upper Reaches of Hanjiang River Basin. *Acta Ecol. Sin.* **2017**, *72*, 2064–2078.
13. Hou, Y.; Lü, Y.H.; Chen, W.P.; Fu, B.J. Temporal variation and spatial scale dependency of ecosystem service interactions:a case study on the central Loess Plateau of China. *Landsc. Ecol.* **2017**, *32*, 1201–1217. [CrossRef]
14. Schirpke, U.; Candiago, S.; Egarter Vigl, L.; Jager, H.; Labadini, A.; Marsoner, T.; Meisch, C.; Tasser, E.; Tappeiner, U. Integrating supply, flow and demand to enhance the understanding of interactions among multiple ecosystem services. *Sci. Total Environ.* **2019**, *651*, 928–941. [CrossRef] [PubMed]
15. Turner, K.G.; Odgaard, M.V.; Bocher, P.K.; Dalggard, T.; Svening, J.C. Bundling ecosystem services in Denmark: Trade-offs and synergies in a cultural landscape. *Landsc. Urban Plan.* **2014**, *125*, 89–104. [CrossRef]
16. Hao, R.; Yu, D.; Sun, Y.; Shi, M. The features and influential factors of interactions among ecosystem services. *Ecol. Indic.* **2019**, *101*, 770–779. [CrossRef]
17. Gonzalez-Redin, J.; Luque, S.; Poggio, L.; Smith, R.; Gimona, A. Spatial Bayesian belief networks as a planning decision tool for mapping ecosystem services trade-offs on forested landscapes. *Environ. Res.* **2016**, *144 Pt B*, 15–26. [CrossRef]
18. Yang, X.N.; Li, J.; Qin, K.Y.; Li, T.; Liu, J.Y. Trade-offs between ecosystem services in Guanzhong-Tianshui economic region. *Acta Geogr. Sin.* **2015**, *70*, 1762–1773.
19. Gong, J.; Liu, D.; Zhang, J.; Xie, Y.; Cao, E.; Li, H. Tradeoffs/synergies of multiple ecosystem services based on land use simulation in a Mountain-Basin Area, Western China. *Ecol. Indic.* **2019**, *99*, 283–293. [CrossRef]
20. Fu, B.J. Trade-off analyses and synthetic integrated method of multiple ecosystem services. *Resour. Sci.* **2016**, *38*, 5–10.
21. Nelson, E.; Sander, H.; Hawthorne, P.; Conte, M.; Ennaanay, D.; Wolny, S.; Manson, S.; Polasky, S. Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models. *PLoS ONE* **2010**, *5*, 14327. [CrossRef]
22. Nelson, E.; Polasky, S.; Lewis, D.J.; Lawler, J.J. Efficiency of incentives to jointly increase carbon sequestration and species conservation on a landscape. *Proc. Natl. Acad. Sci. USA* **2008**, *105*, 9471–9476. [CrossRef] [PubMed]
23. Bagstad, K.J.; Johnson, G.W.; Voigt, B.; Villa, F. Spatial dynamics of ecosystem service flows: A comprehensive approach to quantifying actual services. *Ecosyst. Serv.* **2013**, *4*, 117–125. [CrossRef]
24. Chen, D.S.; Li, J.; Yang, X.N.; Liu, Y. Trade-offs and optimization among ecosystem services in the Weihe River basin. *Acta Ecol. Sin.* **2018**, *38*, 3260–3271.
25. Feng, Y.; Cao, Y.G.; Li, S.P.; Wang, S.F.; Liu, S.H.; Bai, Z.K. Trade-offs and synergies of ecosystem services: Development history and research characteristics. *J. Agric. Resour. Environ.* **2022**, *39*, 11–25.
26. Meng, H.B.; Zhou, Q.G.; Li, M.H.; Zhou, L.; Liu, X.W.; Peng, C.H. Study of the spatiotemporal changes in ecosystem services and trade-offs/synergies relationship in the Three Gorges Reservoir area. *J. Ecol. Rural. Environ.* **2021**, *37*, 566–575.
27. Deng, C.X.; Zhu, D.M.; Nie, X.D.; Liu, C.C.; Li, Z.W.; Liu, J.Y.; Zhang, G.Y.; Xiao, L.H.; Zhang, Y.T. Progress of research regarding the trade-offs of ecosystem services. *Chin. J. Eco-Agric.* **2020**, *28*, 1509–1522.
28. Tian, Y.H. Study on the Synergies and Tradeoffs Among Cultivated Land Ecosystem Services and Its Management Strategies. Master's Thesis, Zhejiang University, Hangzhou, China, 2018.
29. He, J.; Shi, X.; Fu, Y.; Yuan, Y. Spatiotemporal pattern of the trade-offs and synergies of ecosystem services after Grain for Green Program: A case study of the Loess Plateau, China. *Environ. Sci. Pollut. Res. Int.* **2020**, *27*, 30020–30033. [CrossRef]
30. Liu, W.; Zhan, J.; Zhao, F.; Wang, C.; Chang, J.; Asiedu Kumi, M.; Leng, M. Scale effects and time variation of trade-offs and synergies among ecosystem services in the Pearl River Delta, China. *Remote Sens.* **2022**, *14*, 5173. [CrossRef]

31. Foundations, T. *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*; Earthscan: London, UK; Washington, DC, USA, 2010.
32. Garcia, L.; Celette, F.; Gary, C.; Ripoche, A.; Vald'es-Gomez, H.; Metay, A. Management of service crops for the provision of ecosystem services in vineyards: A review. *Agric. Ecosyst. Environ.* **2018**, *251*, 158–170. [CrossRef]
33. Ioannidou, S.C.; Litskas, V.D.; Stavrinides, M.C.; Vogiatzakis, I.N. Linking management practices and soil properties to Ecosystem Services in Mediterranean mixed orchards. *Ecosyst. Serv.* **2022**, *53*, 101378. [CrossRef]
34. Ma, S.; Qiao, Y.; Wang, L.; Zhang, J. Terrain gradient variations in ecosystem services of different vegetation types in mountainous regions: Vegetation resource conservation and sustainable development. *For. Ecol. Manag.* **2021**, *482*, 118856. [CrossRef]
35. Feng, Z.; Jin, X.R.; Chen, T.Q.; Wu, J.S. Understanding trade-offs and synergies of ecosystem services to support the decision-making in the Beijing–Tianjin–Hebei region. *Land Use Policy* **2021**, *106*, 105446. [CrossRef]
36. Yang, X.; Ning, G.; Dong, H.; Li, Y. Soil microbial characters under different vegetation communities in Taihang Mountain area. *J. Appl. Ecol.* **2006**, *17*, 1761–1764.
37. Yang, H.; Cao, J.S.; Hou, X.L. Study on the evaluation and assessment of ecosystem service spatial differentiation at different scales in mountainous areas around the Beijing–Tianjin–Hebei Region, China. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1639. [CrossRef] [PubMed]
38. Xu, X.L. Spatial Distribution of Population in China Kilometer Grid Dataset. Resource and Environmental Science Data Registration and Publication System. 2017. Available online: https://www.resdc.cn/DOI/doi.aspx?DOIid=32 (accessed on 8 December 2024).
39. Xu, X.L. Spatial Distribution of GDP in China Kilometer Grid Dataset. Resource and Environmental Science Data Registration and Publication System. 2017. Available online: https://www.resdc.cn/DOI/doi.aspx?DOIid=33 (accessed on 8 December 2024).
40. Xu, X.L. Spatial Distribution of Terrestrial Ecosystem Service Values in China Dataset. Resource and Environmental Science Data Registration and Publication System. 2018. Available online: https://doi.org/10.12078/2018060503 (accessed on 8 December 2024).
41. Droogers, P.; Allen, R.G. Estimating reference evapotranspiration under inaccurate data conditions. *Irrig. Drain. Syst.* **2002**, *16*, 33–45. [CrossRef]
42. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. FAO Irrigation and Drainage Paper No.56 Crop Evapotranspiration. *Food Agric. Organ. USA Rome* **1998**, *300*, 46.
43. Liu, H.; Zhang, R.Q.; Hao, J.M.; Ai, D. Tupu analysis of land use intensity using semi-variance in Yinchuan Plain. *Trans. Chin. Soc. Agric. Eng.* **2012**, *28*, 225–231, (In Chinese with English Abstract).
44. Zhuang, D.F.; Liu, J.Y. Study on the model of regional differentiation of land use degree in China. *J. Nat. Resour.* **1997**, *12*, 105–111, (In Chinese with English Abstract).
45. Yu, H.Y.; Zhang, F.; Cao, L.; Wang, J.; Yang, S.T. Spatial-temporal pattern of land ecological security at a township scale in the bortala mongolian autonomous prefecture. *Acta Ecol. Sin.* **2017**, *37*, 6355–6369. (In Chinese with English Abstract)
46. Li, T.; Lü, Y.; Fu, B.; Hu, W.; Comber, A.J. Bundling ecosystem services for detecting their interactions driven by large-scale vegetation restoration: Enhanced services while depressed synergies. *Ecol. Indic.* **2019**, *99*, 332–342. [CrossRef]
47. Maes, J.; Egoh, B.; Willemen, L.; Liquete, C.; Vihervaara, P.; Schägner, J.P.; Grizzetti, B.; Drakou, E.G.; Notte, A.L.; Zulian, G.; et al. Mapping ecosystem services for policy support and decision making in the European Union. *Ecosyst. Serv.* **2012**, *1*, 31–39. [CrossRef]
48. Qian, C.Y.; Gong, J.; Zhang, J.Q.; Liu, D.Q.; Ma, X.C. Change and tradeoffs-synergies analysis on watershed ecosystem services: A case study of Bailongjiang Watershed, Gansu. *Acta Geograhica Sin.* **2018**, *73*, 868–879, (In Chinese with English Abstract).
49. Getis, A.; Ord, J.K. The analysis of spatial association by use of distance statistics. *Geogr. Anal.* **1992**, *24*, 189–206. [CrossRef]
50. Anselin, L. Local indicators of spatial association—LISA. *Geogr. Anal.* **1995**, *27*, 93–115. [CrossRef]
51. Gong, J.; Liu, D.Q.; Gao, B.L.; Xu, C.X.; Li, Y. Tradeoffs and synergies of ecosystem services in western mountainous China: A case study of the Bailongjiang watershed in Gansu, China. *Chin. J. Appl. Ecol.* **2020**, *31*, 1278–1288, (In Chinese with English Abstract).
52. Fu, B.J.; Xu, Y.D.; Lyu, Y.H. Scale characteristics and coupled research of landscape pattern and soil and water loss. *Adv. Earth Sci.* **2010**, *25*, 673–681, (In Chinese with English Abstract).
53. Wang, Y.; Dai, E.; Yin, L.; Ma, L. Land use/land cover change and the effects on ecosystem services in the Hengduan Mountain region, China. *Ecosyst. Serv.* **2018**, *34*, 55–67. [CrossRef]
54. Pan, N.H.; Guan, Q.Y.; Wang, Q.Z.; Sun, Y.F.; Li, H.C.; Ma, Y.R. Spatial differentiation and driving mechanisms in ecosystem service value of arid region: A case study in the middle and lower reaches of Shule River Basin, NW China. *J. Clean. Prod.* **2021**, *319*, 128718. [CrossRef]
55. Bennett, E.M.; Peterson, G.D.; Gordon, L. Understanding relationships among multiple ecosystem services. *Ecol. Lett.* **2009**, *12*, 1394–1404. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.