

Article

Dynamic Characteristics of the Water Conservation Functions of Ecosystems in the Yi–Luo River Basin

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Abstract

Water conservation is among the most important ecosystem service functions, and its dynamic changes can reflect the health of regional ecosystems. As one of the ten major tributaries of the Yellow River, the Yi–Luo River in Henan Province plays a significant role in maintaining regional ecological health through the ecosystem water conservation functions of its basin. To explore the characteristics of these functions, this study employed ecosystem transfer matrix and water balance methods to analyze the changes in ecosystem types in the basin and the dynamic changes in the corresponding water conservation functions from 2010 to 2020. The results showed that from 2010 to 2020, the dominant ecosystem types were farmland, forestland, and shrubland, and the main transformations between different ecosystem types were from farmland to urban areas and wetland, from grassland to shrubland, and from shrubland to forestland. The water conservation functions of the different ecosystem types varied significantly, with the average water conservation capacities ranked as follows: forestland > wetland > shrubland > grassland > farmland > others > urban areas. Due to the decreased water conservation depths in the forestland and shrubland ecosystems, the overall water conservation depth decreased over the study period. In addition, the water conservation capacities of the farmland, forestland, and shrubland ecosystems were the highest, reaching 12.94×10^8 , 12.15×10^8 and 9.73×10^8 tons, respectively, accounting for 34.47%, 32.35%, and 25.91% of the total water conservation capacity, respectively. Overall, water conservation in the study area was high in the south and low in the north, and there was an overall decreasing trend over time. Moreover, the regions with critical and important water conservation functions accounted for the largest proportion (47.2%). The critical and important regions were mainly located in the higher altitudes of Luanchuan County and Lushi county, while the moderate and average regions were primarily located in the plains, and weak regions were distributed mainly in the urban area of Luoyang city. Through analysis of the spatiotemporal changes and degree of importance of water conservation functions in the Yi–Luo River Basin, the key regions for ecological protection and construction were identified. The study results can be used to help enhance ecological security in the Yellow River Basin of Henan Province and play a significant role in promoting the regional economy as well as the health and sustainable development of the ecological environment.



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1. Introduction

Water conservation is among the most important ecosystem services, and is critical for flood prevention, water cycle regulation, and soil erosion mitigation. To a certain extent, it reflects the health of regional ecosystems [1] and provides important information for quantifying water resource supply and demand and rationally allocating water resources [2]. Recently, the water conservation functions of different ecosystems, especially in different river basins, have become a research hotspot [3–6]. The initial focus was on typical regions such as the Shiyang River Basin [7,8], which is characterized by arid inland rivers; the farming–pastoral ecotone in the Haihe River Basin [9]; and the Nanming River Basin [10]. Since then, the research scope has expanded to encompass different river basins across China, such as Wulie River Basin [11], Jinsha River Basin [12], Daling River Basin [13], Yongding River Basin [14], and Songjiang River Basin [15]. Relevant studies on the Yellow River Basin have also been conducted but have focused mainly on the Yanhe River Basin [16] and the Heibai River Basin [17]. However, there has been relatively little research on the Yi–Luo River Basin; in particular, no studies have been reported on the Henan section of the Yi–Luo River Basin. The Yi–Luo River is the largest tributary of the Yellow River downstream of the Sanmenxia Reservoir, and it is ecologically important. The human population in the Yi–Luo River Basin is large. Due to anthropogenic activities such as accelerated urbanization and the construction of water conservancy projects, the opposing needs between people and land have become increasingly prominent, posing threats to the water conservation functions within the basin. Therefore, we select the Yi–Luo River Basin as the study area to investigate its water conservation functions.

The water conservation functions of ecosystems are influenced by natural and anthropogenic activities, resulting in spatial heterogeneity and dynamic variability [3–6]. The methods for assessing water conservation functions include water balance, soil storage, comprehensive water storage capacity, runoff regulation, canopy interception residual, rainfall storage, and multivariate regression methods [18–20]. Among them, the water balance method, characterized by simplicity and high accuracy [7,8], is currently the most widely used method and has been employed to study water conservation functions in different regions [21,22]. Therefore, in this study, the water balance method was applied in combination with meteorological and topographic data to investigate the water conservation functions of local ecosystems in the Yi–Luo River Basin as well as their spatial heterogeneity and dynamic changes from 2010 to 2020. The aim of this work was to provide theoretical guidance for soil and water conservation and land management in this basin, as well as scientific support for promoting the regional economy as well as the health and sustainable development of the ecological environment.

2. Materials and Methods

2.1. Study Area

The Yi–Luo River Basin is located in the middle and lower reaches of the Yellow River ($33^{\circ}33'–35^{\circ}5' \text{ N}$, $109^{\circ}45'–113^{\circ}6' \text{ E}$) and is a primary tributary of the Yellow River with abundant water resources (Figure 1). This river basin has a warm-temperate continental monsoon climate, with hot, rainy summers and cold, dry winters. Average temperatures are relatively high in the northeast and low in the southwest. In addition, the basin is located in the second and third step transition zone of China, featuring diverse natural landforms such as medium and low mountains, hills, river valleys, plains, and basins. The topography of the study area is higher in the southwest and lower in the northeast, with the highest elevation reaching 2153 m and the lowest elevation at just 108 m. The Yi–Luo River is composed of the Yi River and Luo River. The Yi River originates from Luanchuan County, Henan Province, and flows from southwest to northeast, with a basin area of 5974.13 km²

in Henan Province. The Luo River originates from Luonan County, Shaanxi Province, and flows from west to east, with a basin area of 9836.92 km² in Henan Province. The two rivers converge at Zaozhuang in Yanshi city and flow into the Yellow River north of Luokou in Gongyi city. The Yi–Luo River flows through Shaanxi Province and Henan Province, with the basin area within Henan Province accounting for 83.74% of the total basin area. The soil types within the basin are diverse, consisting primarily of loam and sandy loam.

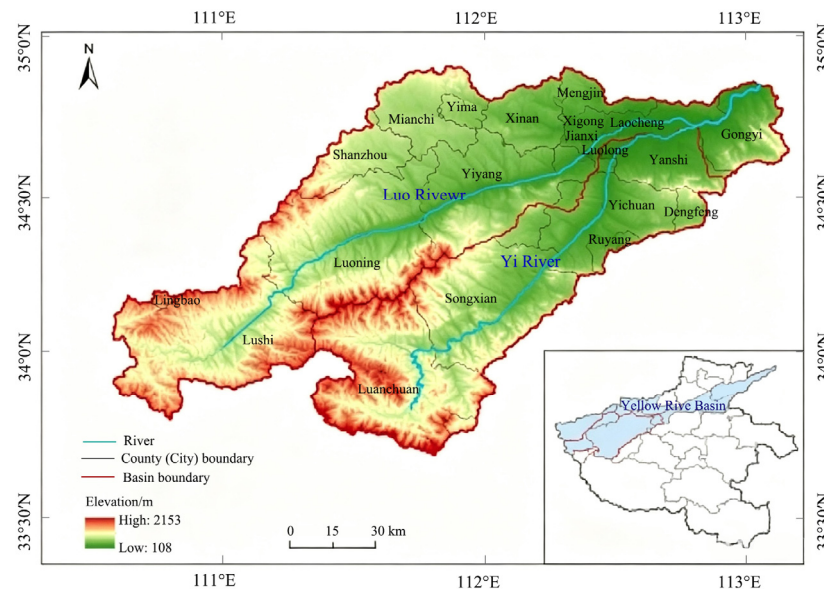


Figure 1. Schematic diagram of the Yi–Luo River Basin.

2.2. Research Methods

The amount of water conservation is an important index to evaluate the water conservation function of an ecosystem. It is closely related to ecosystem type, rainfall, evapotranspiration and surface runoff [13,23]. It plays a significant role in regulating surface runoff, replenishing groundwater, and mitigating seasonal fluctuations in river flow. In this paper, the principle of water balance recommended in the “Technical Specification for National Ecological Status Survey and Evaluation-Ecosystem Service Function Assessment (HJ 1173-2021)” [24] implemented by the Ministry of Ecology and Environment of the People’s Republic of China in August 2021 is used to calculate water conservation as follows:

$$Q_{wr} = \sum_{i=1}^n A_i \times (P_i - R_i - ET_i) \times 10^{-3} \quad (1)$$

Q_{wr} is the amount of water conservation (m³/a). i and n are the ecosystem type and the total number of ecosystem types, respectively. A_i , P_i , ET_i and R_i are the area of ecosystem type i (m²), the rainfall (mm/a), evapotranspiration (mm/a), and the surface runoff (mm/a), respectively.

Evapotranspiration is an important part of the surface water balance and energy cycle. Koichiro Takahashi [23] comprehensively considered the influence of temperature and rainfall on evapotranspiration. This formula is suitable mainly for mid-latitude regions. The calculation formula is as follows:

$$ET_i = \frac{3100P}{3100 + 1.8P^2 \exp\left(-\frac{17.2T}{235+T}\right)} \quad (2)$$

In the equation, ET_i is the evapotranspiration (mm/a), p is the average rainfall (mm/a), and t is the average temperature (°C).

The surface runoff is obtained by the product of rainfall and the surface runoff coefficient. The surface runoff coefficient shows the degree of conversion of rainfall into runoff, which reflects the influence of the ecosystem on rainfall and runoff. This study refers to the research results of similar regions [25–27] and combines the actual situation of the study area to assign the runoff coefficients for different ecosystem types (Table 1).

$$R_i = P \times \alpha \quad (3)$$

where R_i is the surface runoff (mm/a). p and α are the annual rainfall (mm/a) and the surface runoff coefficient, respectively.

Table 1. Runoff coefficients of different ecosystems in Yi–Luo River Basin.

Primary Classification of Ecosystem	Secondary Classification of Ecosystem	Average Surface Runoff Coefficient
Forestland	Broad-leaved forest	3.68
	Coniferous forest	2.7
	Sparse forest	19.2
Shrubland	Broad-leaved shrubland	4.22
	Coniferous shrubland	4.17
	Sparse shrubland	19.2
Grassland	Meadow	8.2
	Steppe	3.94
	Herbosa	9.37
	Sparse grassland	18.27
Wetland	Marsh	0
	Rivers/lakes	0
	Tidal marshes	0
Farmland	Dry farmland	18
	Paddy field	4
	Garden land	9.5
Urban area	Residential areas	60
	Urban green spaces	20
	Industrial, mining, and transportation areas	75
Other land	Bare lands	70

2.3. Ecosystem Transfer Matrix

The ecosystem transfer matrix originates from systems analysis and is used to quantitatively study the processes of transfer direction and quantitative changes between ecosystem types. It can reflect the structural characteristics and spatial pattern changes of the ecosystem in the study area [28–30]. The formula is as follows:

$$S_{ij} = \begin{cases} S_{11} & S_{12} & \dots & S_{1n} \\ S_{21} & S_{22} & \dots & S_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ S_{n1} & S_{n2} & \dots & S_{nn} \end{cases} \quad (4)$$

In the formula, i and j represent the ecosystem types at the beginning and end of the study, respectively, where $i, j = 1, 2, \dots, n$. S_{ij} is the area of the initial ecosystem type i transferred to the final ecosystem type j .

2.4. Importance Evaluation

The degree of water conservation is a key indicator for evaluating the importance of water conservation. Based on the results of water conservation capacity calculations, the importance of water conservation in the Yi–Luo River Basin can be divided into five levels of ecologically important functional areas, namely, weak, general, medium, important and extremely important, by using natural discontinuity point classification and qualitative analysis.

2.5. Data Source and Processing

The related data in this study mainly include meteorological, topographic, and ecosystem type data (Table 2). TM images with a 30 m resolution are used to interpret ecosystem types in 2010, and high-resolution (16 m) image data are used to interpret ecosystem types in 2015 and 2020 (National Remote Sensing Survey and Assessment Project on Ecological Changes, jointly conducted by the Ministry of Ecology and Environment and the Chinese Academy of Sciences). To compare the national ecological status and consistency with the original image resolution, a 16×16 m grid is used. In ArcGIS software (ArcGIS 10.2), the ecosystem type data from 2010 were resampled to obtain data consistent with the resolution of the 2015 and 2020 images. The surface runoff coefficient is assigned by referring to the research results of similar areas and taking into account the actual situation of the study area. The rainfall data, which are based on daily records from the national basic meteorological stations in the Yi–Luo River Basin from 2006 to 2020, are used to calculate the 5-year average rainfall for the three periods of 2006–2010, 2011–2015 and 2016–2020. Evapotranspiration data are calculated based on temperature and rainfall data. All factors were resampled in ArcGIS to obtain a 16×16 m grid, which was processed by geographic registration and correction, and then participated in the calculation and analysis of the water conservation function.

Table 2. Data source.

Data Name	Data Sources
Meteorological data	Daily observation data from national basic meteorological stations, 2006–2020
Topographic data	Geospatial data cloud
Ecosystem type	National remote sensing survey and assessment project on ecological changes, jointly conducted by the Ministry of Ecology and Environment and the Chinese Academy of Sciences

3. Results

3.1. Analysis of Changes in Ecosystem Types

3.1.1. Changes in Ecosystem Types

From 2010 to 2020, the ecosystem types in the Yi–Luo River Basin were dominated by farmland, forestland, and shrubland (Figure 2), followed by grassland and urban area. During this period, the average areas of farmland, forestland, and shrubland in the study area were 6746.76 km^2 , 3754.23 km^2 , and 3251.42 km^2 , respectively, collectively accounting for 86.97% of the total area of the basin. The farmland ecosystem is mainly distributed in Yiyang County, Xinan County, and Yanshi city—located in the central and northern parts of the study area—while forestland and shrubland ecosystems are primarily distributed in Luanchuan County and Lushi County—located in the southern part of the study area (Figure 3). In addition, the areas of various ecosystem types in the study area changed to varying degrees during this period. Among them, the areas of shrubland, urban area, forestland, and wetland all increased (Figure 2), with the area of shrubland increasing the most, from 3130.97 km^2 to 3343.69 km^2 (approximately 6.79%), whereas the areas of

urban areas, forestland, and wetland increased by 192.36 km², 140.14 km², and 73.69 km², respectively. The areas of grassland, farmland, and other land-use types tended to decrease (Figure 2). In particular, the area of grassland decreased the most, from 1144.21 km² to 773.09 km² (approximately 32.44%), followed by that of farmland, which decreased by 241.92 km².

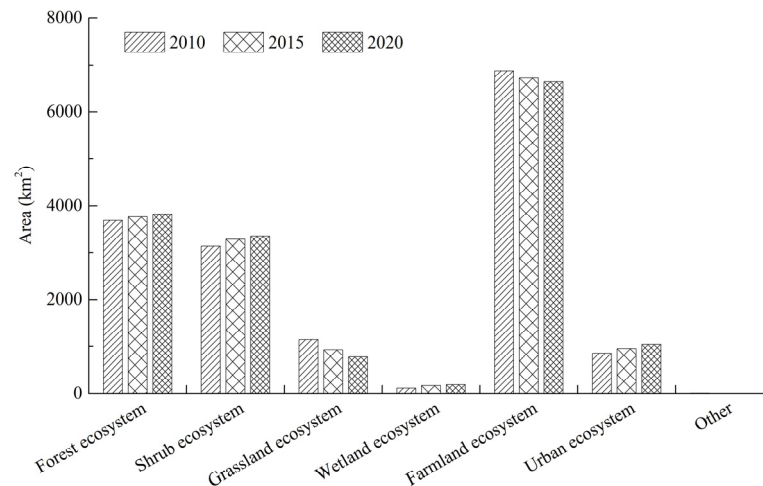


Figure 2. Changes in the area of different ecosystems in the Yi-Luo River Basin, 2010–2020.

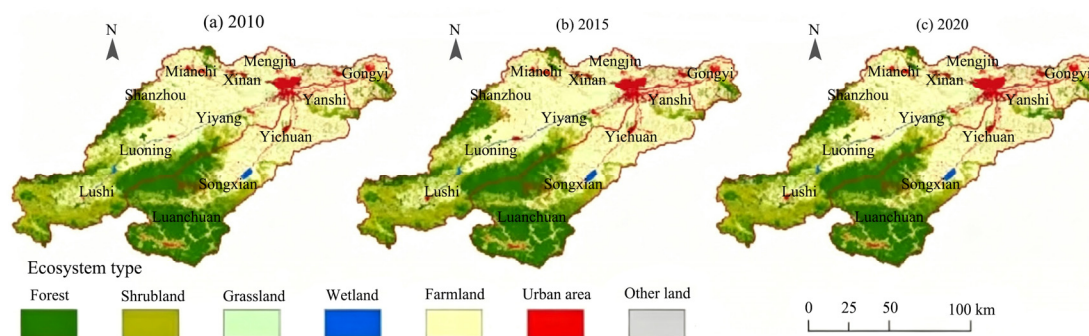


Figure 3. Spatial distribution of different ecosystem types in Yi-Luo River Basin from 2010 to 2020.

3.1.2. Ecosystem Type Transfer

The ecosystem type transfer matrix was used to statistically analyze the area of each ecosystem type transferred in and out of the Yi-Luo River Basin from 2010 to 2020. As shown in Table 3, the transferred-in area of farmland in the basin was 236.28 km², mainly transferred from grassland and urban areas; the transferred-out area of farmland was 477.29 km² (2.02 times the transferred-in area), which was mainly transferred to urban areas and accounted for 58.45% of the total transferred-out area. The transferred-in area of grassland was 91.87 km², while its transferred-out area was 463.04 km², 5.04 times the transferred-in area, which was mainly transferred to shrubland (71.40%). The transferred-in area of shrubland ecosystem was 1.85 times the transferred-out area, which was mainly transferred from grassland to forestland (191.56 km²), accounting for 76.27% of the transferred-out area. The amount of forest ecosystem transferred in was 2.04 times that transferred out, and the main transferred-in area came from shrub ecosystem, indicating that the area of grassland ecosystem decreases and the area of shrub and forest ecosystems increases, mainly showing the trend of grassland turning to shrub and shrub turning to forest ecosystem. With the enhancement of the ecological consciousness of the government and people in the region, a series of key ecological construction projects have been implemented, such as the returning

farmland to forestland project and the natural forest protection project, which has increased the areas of forest and shrub ecosystems and enhanced vegetation coverage.

Table 3. The transfer matrix among different ecosystem types in the Yi–Luo River Basin from 2010 to 2020.

2020	2010							Total
	Forest Ecosystem	Shrub Ecosystem	Grassland Ecosystem	Wetland Ecosystem	Farmland Ecosystem	Urban Ecosystem	Other	
Forest ecosystem	3543.57	191.56	32.15	2.05	41.10	7.92	0.31	3818.65
Shrub ecosystem	64.13	2879.84	330.60	1.59	57.99	9.36	0.18	3343.69
Grassland ecosystem	56.61	13.17	681.18	0.84	20.45	0.77	0.02	773.04
Wetland ecosystem	0.84	3.08	1.68	99.22	77.83	2.44	4.49	189.58
Farmland ecosystem	9.82	36.91	90.83	7.36	6404.78	90.38	0.98	6641.05
Urban ecosystem	3.38	6.31	7.74	4.82	280.10	737.64	0.95	1040.93
Other	0.15	0.11	0.04	0.01	0.72	0.06	2.30	3.40
Total	3678.51	3130.97	1144.21	115.89	6882.97	848.57	9.22	15,810.34

The analysis of the transfer of ecosystem types in the Yi–Luo River Basin from 2010 to 2020 shows that grassland and farmland ecosystems are mainly transferred out (Table 3): the grassland is mainly transferred to shrubland and the farmland is mainly transferred to urban areas. Forestland, shrubland, wetland and urban areas are mainly transferred in: forestland is mainly transferred from shrubland, shrubland is mainly transferred from grassland, and wetland and urban areas are mainly transferred from farmland. The transfer matrix of ecosystem types was used to quantitatively analyze the source and destination of the increase or decrease in each ecosystem type, and intuitively reflects the composition and change mechanism of the ecosystem types in Yi–Luo River Basin, which has certain guiding significance for future rational planning and resource protection of the basin.

3.2. Assessment of Water Conservation Function

3.2.1. Spatial–Temporal Distribution of Water Conservation

From 2010 to 2020, the water conservation capacity of Yi–Luo River Basin changed significantly (Figure 4), with a slight initial increase followed by a decrease (Table 4). In 2010, the water conservation capacity of the Yi–Luo River Basin was 4.156 billion tons, and the water conservation depth was 262.88 mm. In 2015, the water conservation capacity of this basin increased slightly to a total of 4.225 billion tons. In 2020, the water conservation capacity was 3.761 billion tons, a 9.5% decrease compared with that in 2010. The spatial distribution characteristics of water conservation capacity in the study area in 2010, 2015, and 2020 were generally consistent (Figure 4), with high values in the south and low values in the north. Regions with high water conservation capacity were concentrated mainly in Luanchuan County in the southern part of the study area, while regions with low water conservation capacity were primarily distributed in Luoyang city and Yanshi city in the northern part of the study area.

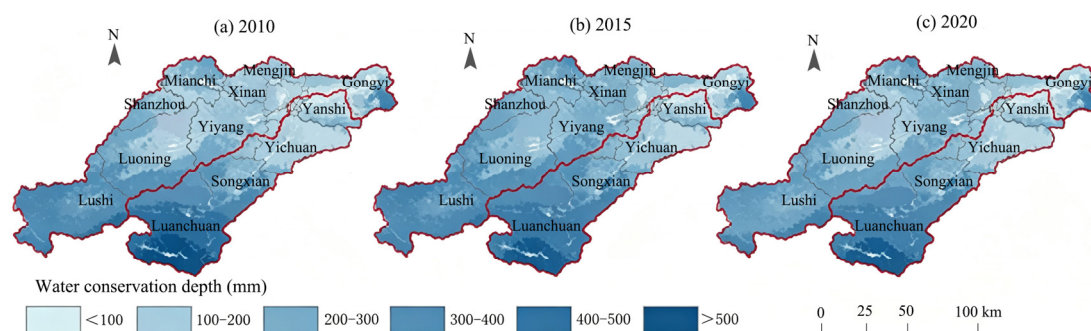


Figure 4. Spatial distribution of water conservation depth in Yi–Luo River Basin from 2010 to 2020.

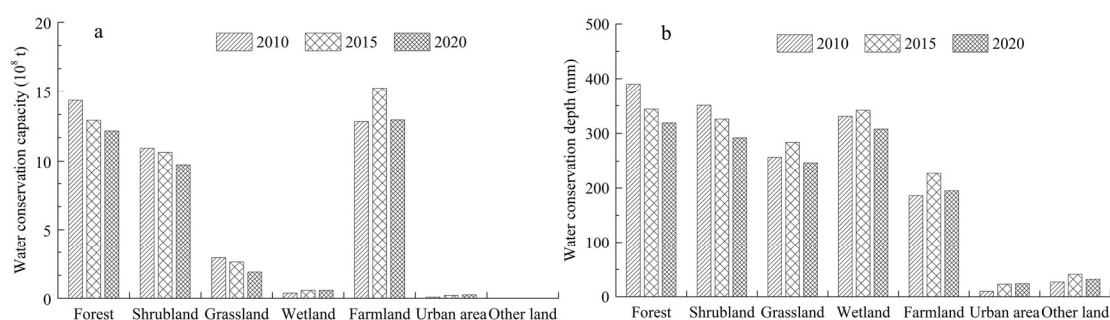
Table 4. The water conservation capacity of Yi–Luo River Basin.

Basin	Area (hm ²)	2010		2015		2020		Average for 2010–2020	
		Water Conservation Capacity (10 ⁸ t)	Water Conservation Depth (mm)	Water Conservation Capacity (10 ⁸ t)	Water Conservation Depth (mm)	Water Conservation Capacity (10 ⁸ t)	Water Conservation Depth (mm)	Water Conservation Capacity (10 ⁸ t)	Water Conservation Depth (mm)
Yi–Luo River	1,581,105	41.56	262.88	42.25	267.26	37.61	237.93	40.47	256.02
Yi River	597,413	18.59	311.10	17.02	284.98	16.15	270.33	17.25	288.80
Luo River	983,692	22.97	233.53	25.23	256.48	21.46	218.21	23.22	236.07

The area of the Luo River Basin is 1.65 times that of the Yi River Basin, and the water conservation capacity is 1.24 times that of the Yi River Basin. From 2010 to 2020, the water conservation capacity of the Luo River Basin first increased and then decreased (Table 4), changing from 22.97×10^8 tons in 2010 to 25.23×10^8 tons in 2015 and then decreasing to 21.46×10^8 tons in 2020. Similarly, the water conservation depth increased from 233.53 mm to 256.48 mm and then decreased to 218.21 mm, representing an overall decrease of 6.57%. From 2010 to 2020, the water conservation capacity of the Yi River Basin showed a gradual downward trend (Table 4), decreasing from 18.59×10^8 tons in 2010 to 16.15×10^8 tons in 2020, and the corresponding water conservation depth decreased from 311.10 mm in 2010 to 270.33 mm in 2020, representing an overall decline of 13.11%.

3.2.2. Water Conservation Capacities of Different Ecosystem Types

There were large differences in the water conservation capacities of different ecosystem types in the Yi–Luo River Basin in 2010, 2015, and 2020 (Figure 5a). In 2010, the forest ecosystem had the highest water conservation capacity, at 14.34×10^8 tons, accounting for 34.55% of the total water conservation capacity. In 2015 and 2020, the water conservation capacity of farmland was the largest, followed by that of forestland and shrubland. In 2020, the water conservation capacities of farmland, forestland, and shrubland ecosystems in the basin were 12.94×10^8 , 12.15×10^8 , and 9.73×10^8 tons, respectively, accounting for 34.47%, 32.35%, and 25.91% of the total water conservation capacity, respectively. In addition, considerable differences in water conservation depth were detected among the different ecosystem types in the Yi–Luo River Basin (Figure 5b). In 2020, forests had the largest water conservation depth (318.68 mm), followed by wetland (307.77 mm), shrubland (292.48 mm), grassland (246.57 mm), and farmland (194.94 mm), and other ecosystems and urban areas had the smallest water conservation depths, at 31.63 and 23.77 mm, respectively. From 2010 to 2020, the water conservation depth in the Yi–Luo River Basin tended to decrease overall, mainly due to the substantial reduction in the water conservation depths of forestland and shrubland, which decreased by 18.37% and 16.59%, respectively.

**Figure 5.** Water conservation capacity of different ecosystem types in the Yi–Luo River Basin from 2010 to 2020.

3.2.3. Effects of Climate Factors on the Water Conservation Function

Among the climatic factors, rainfall is the key factor affecting the water conservation capacity of the study area. As shown in Figure 6, from 2010 to 2020, the water conservation capacity of the Yi–Luo River Basin showed a trend of increasing first and then decreasing (Figure 6a), and the rainfall showed a decreasing trend (Figure 6b). Overall, there was a positive correlation between rainfall and water conservation (Figure 6c). As shown in Figure 7, the water conservation reduction area accounted for 68.65% of the total study area from 2010 to 2020, and the water conservation increase area accounted for 31.35% of the total study area. Among them, the reduction area from 2010 to 2015 accounted for 47.18% of the study area, and that from 2015 to 2020 accounted for 85.4% (Figure 7A). From 2010 to 2020, the overall rainfall in the study area decreased by 51.34%, with a 49.22% reduction in the first five years and a 65.45% reduction in the second five years (Figure 7B), which was the same as the change trend of the water conservation function.

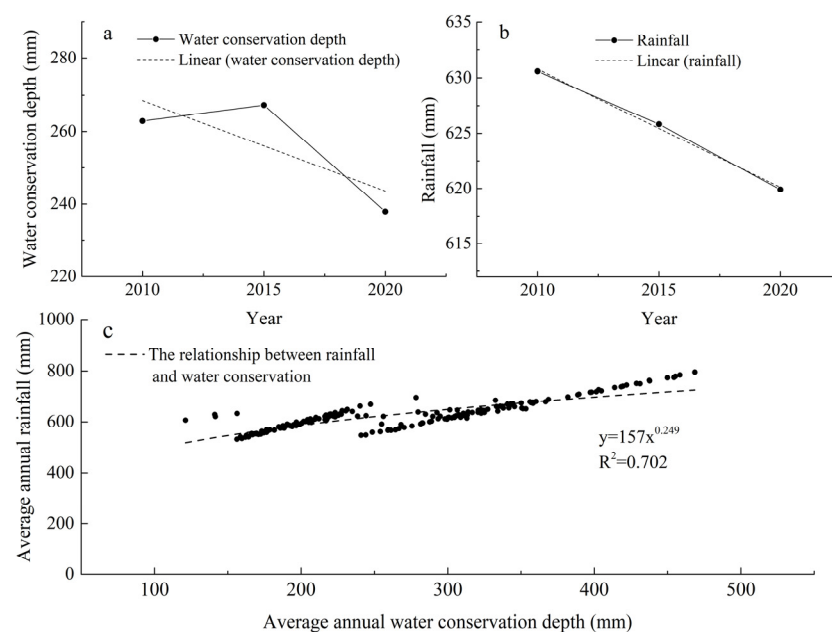


Figure 6. Water conservation depth and rainfall in the Yi–Luo River Basin from 2010 to 2020 ((a): changes in water conservation depth over time; (b): changes in rainfall over time; (c): the relationship between average annual rainfall and average annual water conservation depth).

From 2010 to 2015, the water conservation function of Luanchuan County decreased significantly, with a change rate $> -10\%$ (Figure 7A(a1)), and the change rate of rainfall was $> -10\%$ (Figure 7B(b1)). From 2015 to 2020, water conservation function in Luanchuan County, which had significantly declined, increased compared with that in the previous five years, while that of Yiyang County and Xinan County, which had previously shown growth, now experienced a decline (Figure 7A(a2)). This pattern is similar to the spatial distribution of rainfall changes (Figure 7B(b2)), showing that changes in rainfall affect water conservation. On the whole, the water conservation function of Yi–Luo River Basin changed greatly from 2010 to 2020 (Figure 7A(a3)). In the study area, the east of Xinan county, the north of Ruyang county, the west of Gongyi city, Yiyang county and Dengfeng city showed an increasing trend, and the remaining areas showed a decreasing trend, especially in Luoyang city (the north of the study area) and Luanchuan County (the south of the study area) where it was most obvious ($> \pm 10\%$), which was consistent with the change trend of rainfall in this area (Figure 7B(b3)).

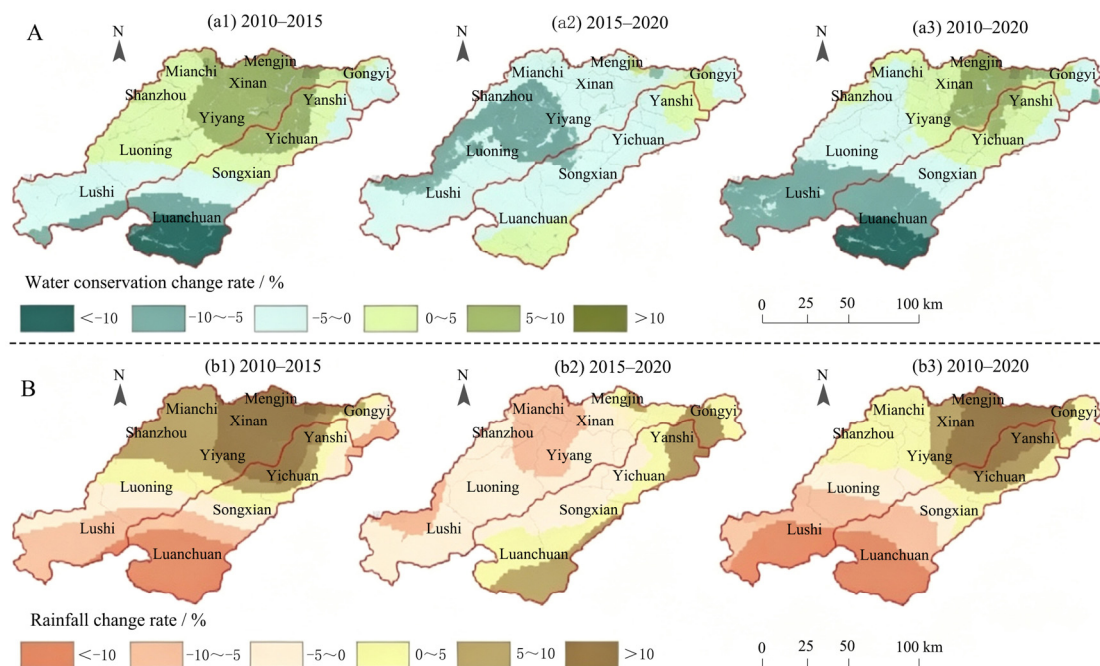


Figure 7. Change rates of water conservation (A) and rainfall (B) in the Yi-Luo River Basin from 2010 to 2020.

3.2.4. Evaluation of the Importance of Water Conservation

Based on the spatial distribution characteristics of water conservation in the Yi-Luo River Basin from 2010 to 2020, and with reference to relevant research findings [26], the degree of importance of water conservation in the Yi-Luo River Basin was divided into five levels: level 1 (weak: <100 mm), level 2 (general: 100–200 mm), level 3 (moderate: 200–300 mm), level 4 (important: 300–400 mm), and level 5 (critical: >400 mm). These classification levels were used to analyze changes in the importance of water conservation in the study area from 2010 to 2020 (Table 5). The results showed there are relatively large fluctuations in the water conservation capacity and areas of the regions with different importance levels. The areas and water conservation capacities of critical, general, and important regions decreased continuously, with the relative areas decreasing by 9.63%, 9.07%, and 5.68%, respectively (Table 5), and the water conservation capacities decreasing by 7.53×10^8 tons, 2.19×10^8 tons, and 3.58×10^8 tons, respectively. The water conservation capacity and area of the moderate region increased continuously, with the relative area increasing by 23.61% and the water conservation capacity increasing by 9.28×10^8 tons, or 26.04% (Table 5).

Table 5. Assessment and classification of water conservation function in the Yi-Luo River Basin, 2010–2020.

Level	Standard (mm)	Classification	Total Water Conservation (10^8 t)					Area (km^2)				
			2010	2015	2020	Average Proportion (%)	Proportion Change (%)	2010	2015	2020	Average Proportion (%)	Proportion Change (%)
Level 1	<100	Weak	0.01	0.00	0.00	0.01	−0.03	857	912	976	5.80	0.75
Level 2	100–200	General	8.95	2.18	6.76	14.92	−3.56	5265	1253	3835	21.87	−9.07
Level 3	200–300	Moderate	9.27	16.78	18.65	36.84	26.04	3772	6816	7498	38.21	23.61
Level 4	300–400	Important	13.4	22.17	9.82	36.57	−7.47	3813	6542	2918	28.04	−5.68
Level 5	>400	Critical	9.84	1.04	2.31	10.63	−18.04	2070	255	551	6.08	−9.63

In terms of spatial distribution, the importance of water conservation in the Yi-Luo River Basin decreased from south to north (Figure 8). The critical and important regions were mainly located in Luanchuan County, Lushi County, and the southern part of Song

County. This range primarily covers the Xiong’ershan Nature Reserve, whose rich vegetation types, high coverage, and good soil structure contribute to a strong regional water conservation capacity. The moderate and general regions were located primarily on the plains, which are dominated by farmland ecosystems and characterized by severe soil erosion and high evaporation, with an average water conservation capacity. The weak regions were distributed in the urban area of Luoyang city, where the vegetation coverage is low, the degree of surface hardening is high, and the water conservation capacity is relatively poor.

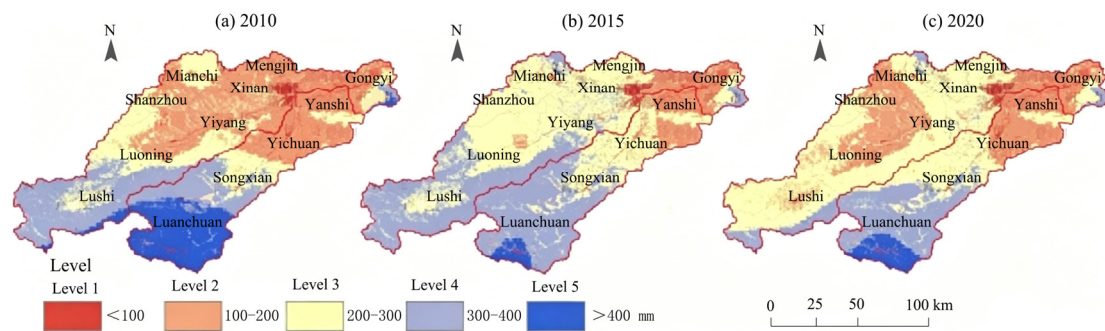


Figure 8. Spatial distribution of the importance of water conservation in the Yi–Luo River Basin from 2010 to 2020.

4. Discussion

4.1. Comparative Analysis with Other Studies

The water conservation amount of the Yi–Luo River Basin is 40.47×10^8 t, and the water conservation depth is 256.02 mm. From 2010 to 2020, the spatial distribution of the water conservation function in the Yi–Luo River Basin is generally high in the south and low in the north, and the higher values are mainly concentrated in Luanchuan County in the south; the lower values are mainly distributed in the northern Luoyang city, Yanshi city and so on. These findings are similar to the spatial distribution patterns of water conservation in Henan Province reported by Xiao Juncang et al. [27], Henan Province reported by Liu Tianke et al. [31] and the Funiu Mountain area reported by Zhang Jingjing [32]. However, Zhang Jingjing [32] believes that Luanchuan County has a high altitude, high vegetation coverage, and high evaporation, and is located in the middle and upper reaches of the river, which is not conducive to water storage and water conservation; thus, the water conservation capacity of this area is weak. Different from this study, the selection area used in Zhang Jingjing’s study was dominated by forest ecosystems and flowed through more rivers, and the influencing factors were different. The regional topography and geomorphology selected in this paper are diverse. Within the study area, Luanchuan County has a relatively high water conservation capacity.

4.2. The Impact of Transformation Among Different Ecosystem Types on Water Conservation

The water conservation functions of different ecosystem types are different, and the soil physical and chemical properties and infiltration amount of different ecosystem types are different, which affects the water supply [33]. From 2010 to 2020, the Yi–Luo River Basin was dominated by farmland, forestland and shrubland ecosystems, accounting for 86.97% of the total area. The water conservation depths of different ecosystem types were forestland > wetland > shrubland > grassland > farmland > other > urban. These results are essentially similar to those of Xiao Juncang [27] on Henan Province and Liu Tianke [31] on the Yellow River Basin in Henan Province. From 2010 to 2020, the ecosystem changes in the Yi–Luo River Basin were as follows: farmland turned to towns, followed by wetlands, shrublands,

forests, and grasslands; grassland turned to shrubland; shrubland turned to forestland; the wetland was mainly transferred from farmland. The areas of grassland, farmland and other ecosystems in the Yi–Luo River Basin showed a decreasing trend. The areas of shrubland, urban, forestland and wetland ecosystems presented an increasing trend. The decrease in farmland ecosystem area and the increase in urban ecosystem area are mainly due to the development of urbanization, urban expansion, power station construction and highway construction. The increase in forestland and shrubland ecosystem area is mainly due to the implementation of the project of returning farmland to forestland and the natural forest protection project. The increase in the area of wetland ecosystem is mainly due to the construction of the Yellow River Wetland Nature Reserve [28]. Liu Jiao's study of the Jinsha River [12] and Hu Shengjun's study of Qiaojia County in Yunnan [34] also reached similar conclusions.

4.3. The Impact of Climate on Water Conservation Changes

The change trend of climatic factors in the Yi–Luo River Basin is basically the same as that of water conservation in the basin. Therefore, climatic factors can be considered the main factors influencing the water conservation function in the Yi–Luo River Basin. These results are consistent with the conclusions reached for the Beijing–Tianjin–Hebei region [35], Bailong River Basin [36], Wulie River [11] and other research areas. Under normal circumstances, the water conservation functions of a region decline with declining rainfall. However, despite a decrease in rainfall from 2010 to 2015, the water conservation function of the Yi–Luo River Basin showed a slight upward trend, and the water conservation function of other ecosystems, except forest and shrub ecosystem types, showed an upward trend. The reason for this situation may be that the area involved in the study area is large, and the reduction in rainfall during this stage is mainly concentrated in forestland and shrubland ecosystems. The total rainfall in the other ecosystem types changed little or showed an upward trend; this variation in rainfall was not enough to affect the overall change in the water conservation function of other ecosystem types. In this paper, the meteorological time series data from 2006 to 2020 were used to study the water conservation function. The climate has a certain degree of volatility. The periodic fluctuations in the climate and their contributions to the water conservation function of the Yi–Luo River Basin still need to be studied in the future.

4.4. Impact and Implications

The water conservation function of the Yi–Luo River Basin plays a crucial role in ensuring the health of the regional ecological environment. From 2010 to 2020, the areas classified as “extremely important” and “important” for water conservation in the study area decreased by 9.63% and 5.68%, respectively, leading to a downward trend in the overall water conservation capacity of the study area. This finding indicates that in some parts of the study area, it is still necessary to adjust ecosystem types to increase the area proportions classified as “extremely important” and “important”. Water conservation capacity varies significantly among different ecosystem types. Between 2010 and 2020, the area of grassland ecosystems in the study area decreased by approximately 32.44%. Given that grassland ecosystems possess relatively high water conservation capacity, increasing the area of grasslands in the study area would have a significant impact on enhancing the region's overall water conservation capacity. In addition, many factors influence the water conservation function of ecosystems. This study primarily focused on natural factors and did not consider other relevant factors, such as regional economic conditions and national policies. Future research should fully account for the combined effects of various factors

on ecosystem water conservation to conduct a more comprehensive study of the dynamic changes in water conservation within the Yi–Luo River Basin.

In addition, this study employed the water balance method, combined with meteorological and topographic data, to investigate the water conservation function of ecosystems in the Yi–Luo River Basin from 2010 to 2020, as well as their spatial heterogeneity and dynamic changes. These findings are generally consistent with existing results. Although the water balance method offers advantages such as being intuitive and straightforward, providing relatively reliable results, and being widely applied, it still has shortcomings compared with current advanced models—such as the INVEST model (water conservation module)—including a heavy reliance on empirical formulas and widespread spatial homogenization. In addition, this study assigned runoff coefficients of different ecosystem types in the study area by referencing research findings from similar regions and incorporating the actual conditions of the study area, yielding relatively accurate results. However, whether these runoff coefficients are applicable to other basins still needs further verification. In the future, it will remain necessary to validate and optimize runoff coefficients for different ecosystems in different basins, and to consider applying more comprehensive hydrological models to conduct a more in-depth exploration of the water conservation function in the study area, with the aim of better promoting the health and sustainable development of the regional economy and ecological environment.

5. Conclusions

This study investigated the dynamic changes in the water conservation of ecosystems within the Yi–Luo River Basin. The conclusions are as follows: (1) The ecosystem types in the Yi–Luo River Basin are mainly farmland, forestland and shrubland. The area of shrubland, urban, forestland and wetland ecosystems showed an increasing trend from 2010 to 2020. The area of grassland, farmland and other ecosystems showed a decreasing trend. (2) The spatial distribution pattern of the water conservation function in the Yi–Luo River Basin remained largely consistent from 2010 to 2020. The area with high water conservation capacity is mainly located in Luanchuan County, which features high mountains, steep slopes and high vegetation coverage. The area with low water conservation capacity is mainly concentrated in Luoyang urban area, which has small topographic relief and low vegetation coverage. In terms of time, the water conservation amount in the Yi–Luo River Basin decreased by 395 million tons from 2010 to 2020, with the water conservation amount of the Yi River Basin declining by 13.11% and that of the Luo River Basin decreasing by 6.57%. (3) From 2010 to 2020, the water conservation function of different ecosystem types in the Yi–Luo River Basin is quite different. The water conservation depth of forest ecosystem is the largest, at 318.68 mm, followed by that of wetland, shrubland, grassland, farmland, other areas and urban areas. Although the water conservation capacity of forestland and shrubland ecosystems is strong, the water conservation depth of forestland and shrubland ecosystems decreased significantly from 2010 to 2020, making the overall water conservation capacity of the study area show a downward trend. (4) From 2010 to 2020, in the areas with large changes in water conservation in the Yi–Luo River Basin (>10%), the change trend of water conservation was consistent with that of rainfall, and rainfall was positively correlated with water conservation. (5) In terms of the statistics of the importance of water conservation function from 2010 to 2020, the most obvious fluctuation occurred in the middle area of water conservation. The proportion of this area increased by 23.61%, and the proportion of total water conservation increased by 26.04%. From 2010 to 2020, the extremely important and important water conservation areas accounted for approximately half of the total area. However, compared with 2010, the proportion of extremely important and important areas in 2020 decreased by 9.63%.

and 5.68%, respectively, and the corresponding water conservation capacities decreased by 18.04% and 7.47%, respectively, which resulted in a downward trend in the overall water conservation of the study area.

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