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Optimization of Rural Residential Areas in Flood Detention Basins Based on Dual Minimum Accumulation Resistance Model: A Case Study of Xun County in Central China

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Abstract: Optimizing rural residential areas (RRAs) in environmentally fragile areas such as flood detention basins is of great significance for improving the human–land relationship and achieving sustainable rural development. This study took Xun County in central China as a case study, established a dual minimum cumulative resistance model (DMCR) that considered the dual factors of natural attributes and policy regulations to evaluate the optimization resistance of RRAs and determined the optimization directions and strategies accordingly. The main results are: (1) RRAs are relatively small and scattered, and there are spatial conflicts with policy regulations such as flood detention basin and urban development boundaries. (2) The spatial difference in optimization resistance of RRAS is higher in the central and northern towns and lower in the western and eastern towns. The factors with significant effects include policy resistance, location resistance, and production resistance. (3) The optimization of RRAs is divided into three directions: annexation or evacuation, consolidation and improvement, and clustering and upgrading, with their respective area proportions of 31.17%, 48.12%, and 20.72%. (4) RRAs in the direction of clustering and upgrading allow for moderate expansion; RRAs in the direction of consolidation and improvement achieve smart reduction through the renovation of homesteads; RRAs in the direction of annexation or evacuation are gradually integrated into the urban area in the suburbs and completely demolished in the outer suburbs.

Keywords: rural residential areas; optimization; minimum cumulative resistance; policy regulation; flood detention basin

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1. Introduction

RRAs refer to the main settlement places formed by the gathering of rural residents for production and living need [1,2]. As multifunctional and complex spaces, rural areas have more frequent flows of population, production factors, and information in the era of globalization [3]. The rapid development of global urbanization has triggered a drastic differentiation and reorganization of RRAs, posing a series of problems and challenges to sustainable rural development, such as the non-agriculturalization of rural production factors [4], the lagging construction of public infrastructure [5], the extensive construction land use [6], and the deterioration of living environment [7]. Meanwhile, due to the decentralization of rural population and lower income, RRAs are generally dispersed and have lower building quality compared to cities [8,9]. When facing increasingly frequent natural disasters such as droughts, floods, and earthquakes, their resilience is lower and

the losses suffered is greater [10,11]. These issues are reflected in the rural economy and society, leading to a series of difficulties in rural spatial governance, causing rural decline, and restricting the development of urban–rural integration. As an important component of the rural regional system, the optimization of RRAs can improve the allocation of rural development factors, alleviate conflicts between rural construction and ecosystems, enhance the resilience of rural settlements in ecologically fragile areas to natural disasters, and achieve high-quality rural development.

A large amount of research has been conducted on RRAs, mainly focusing on the morphological changes [12,13], distribution characteristics [14], layout optimization [15], spatial reconstruction [16], and type identification [17]. The spatial optimization of RRAs as part of rural reconstruction seems to be a positive response to the dilemmas of rural development [18], gradually becoming a hot topic in in rural geography research. There were three mainstreams for spatial optimization of RRAs in previous research. Firstly, the development capacity of RRAs has been evaluated based on their comprehensive influence, layout suitability, and development potential, and divided the development types and optimization paths of RRAs based on the interaction relationships within the regional system [19,20]. Secondly, the direction and strategies for relocating RRAs have been proposed based on dominant factors such as farming conditions, accessibility of public infrastructure, rural livability, or intervillage social connections [21,22]. Thirdly, computer fast iteration technology has been utilized to dynamically simulate and optimize the layout, combining geographic spatial analysis methods with ant colony algorithm and genetic algorithm models to continuously optimize the spatial layout scheme of RRAs [23,24]. The minimum cumulative resistance (MCR) model was proposed by Dutch ecologist Knaapen in 1992, which expresses the minimum value of resistance that a biological species needs to overcome to reach its "target" location from its "source" point. Later [25], it was revised by some scholars and used in research on the suitability evaluation of RRAs [26] and the construction of ecological security patterns [27]. The current research on optimizing RRAs using the MCR model mainly considers the resistance of natural and geographical conditions attributes. With the accumulation of practical experience and the advancement of engineering technology, the limitations of natural and geographical conditions on the layout of RRAs are weakening, and the influence of policy regulations formulated by government departments is becoming stronger. From the perspective of residential suitability, the integration of humanistic policy regulations into the spatial reconstruction of RRAs needs to be strengthened.

As one of the fastest urbanizing countries in the past decades, China has experienced a huge amount of rural–urban migration, which has made the socio-economic changes in rural China the most prominent rural transformation in the world. The massive outflow of population has led to the dilemma of degradation of development capacity and the popularization of "hollow villages" in China's rural areas, similar to the phenomenon of "empty territories" or "sparsely populated territories" in rural areas of most European countries [28,29]. These issues have led to increasingly fragile and unstable rural development, and have also attracted sustained attention from global scholars on the optimization of RRAs in China. The research on optimization of RRAs in China covers residential suitability evaluation [30,31], optimization directions [32], and optimization methods improvement [33]. The research area was mainly concentrated in the central eastern plains [34] and western plateaus [35], with the research units gradually focusing on small and medium-sized counties, towns, and villages [36]. Chinese RRAs have undergone long-term expansion and widely distributed in various geographical units. Among them, RRAs in ecologically fragile areas such as mountainous areas and flood detention basins have long faced harsh living conditions and high risks of natural disasters, and urgently need to be optimized [37]. Flood detention basins refer to low-lying areas and lakes that temporarily store floodwaters outside the back surface of river embankments, including flood diversion outlets. Most of them are places where rivers were flooded and stored in history. As an emergency area for flood control, there are still a large number of residents

living in the flood detention basins. When a flood disaster occurs, the probability of RRAs in the flood detention basins being flooded is higher, and the task of emergency shelter and refuge is also more arduous. Therefore, it is necessary to optimize the RRAs in the flood detention basins according to the special flood emergency situation. Targeted research on the optimization of RRAs in flood detention basins, taking into account both natural attributes and policy regulation, should be conducted to enhance their resilience.

This study took Xun County (with about one-third of its territory being flood detention basin) in central China as the research area, and established a DMCR model with dual factors of natural attributes and policy regulations to evaluate the residential suitability of RRAs. Then, the optimization directions of RRAs were determined and corresponding optimization strategies were proposed. We hope the research results can provide a scientific basis for reconstructing the spatial pattern of RRAs, enhance the resilience of RRAs in flood detention basin to cope with natural disasters, and promote rural sustainable development.

2. Study Area

Xun County is located in the northern part of Henan Province in central China (114°14′52″~114°45′12″ E and 35°26′00″~35°50′42″ N). The old course of the Yellow River passes through its east and now belongs to the Haihe River Basin (the largest water system in North China and one of the seven major rivers in China). Xun County has a total area of 954.99 km^2 and governs 11 townships, including seven towns (Shantang (ST), Tunzi (TZ), Xinzhen (XZ), Xiaohe (XH), Weixian (WX), Wangzhuang (WZ), and Baisi (BS)), and four street offices (Weixi (WXJ), Xunzhou (XZJ), Liyang (LYJ), and Pishan (PSJ)) in the urban area. The overall terrain is relatively low, with low hills in the west and plains accounting for 85% of the entire area in the central and eastern parts. The flood detention basins designed for regulating and controlling floods are widely distributed in the central and southern parts of Xun County, with an area of 317.65 km^2, accounting for 33.26% of the total area (Figure 1). Therefore, when encountering strong floods, there will be a high risk of large-scale flooding within its territory.

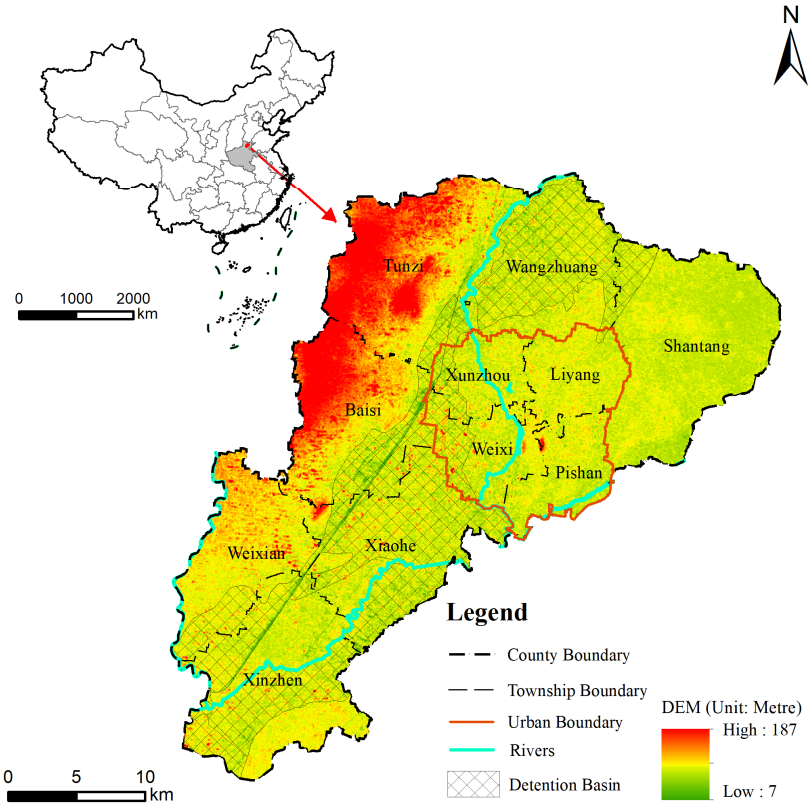


Figure 1. Location and topography of Xun County.

In 2021, the GDP of Xun County was USD 4.61 billion, with a proportion of 10.7:54.2:35.1 for the primary, secondary, and tertiary industries. The total population was 626.3 thousand, including 390.45 thousand rural residents. The current urbanization rate in Xun County is relatively low, but it has experienced rapid urbanization in the past decade, with the urbanization rate increasing from 23.23% in 2010 to 37.67% in 2021. From 2010 to 2021, the rural population in Xun County continued to decrease, from 510.4 thousand in 2010 to 390.44 in 2021, a decrease of 23.50%. However, the area of RRAs has not decreased synchronously with the rural population, but rather an initial increase followed by a decrease, with an overall decrease of only 2.17% or 2.26 km^2 (Figure 2a). Due to the lack of coordinated changes between the rural population and RRAs in Xun County, the per capita RRAs showed a significant increase, from 204.03 m^2 in 2010 to 260.94 m^2 in 2021 (Figure 2b). The utilization of RRAs is becoming increasingly extensive.

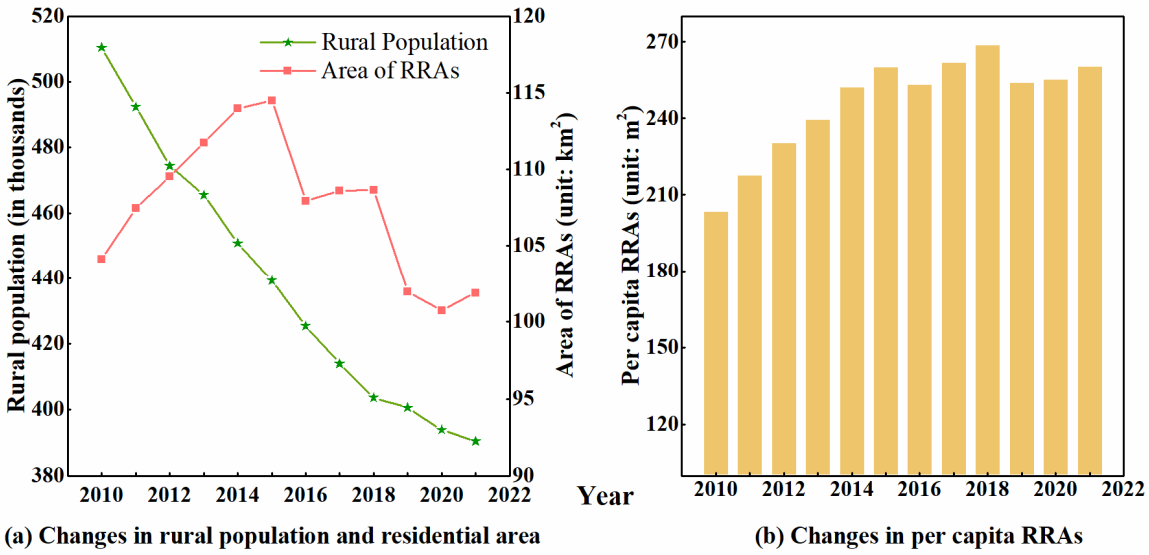


Figure 2. Changes in rural population and RRAs in Xun County from 2010 to 2021.

Aligned with the continuous loss of rural population, there have been widespread signs of decline in the rural areas of Xun County. There are three main manifestations: (1) The flow of young and middle-aged population to cities has led to a large number of left behind elderly and children in rural areas lack necessary care. (2) The decrease in rural population has led to a large number of abandoned houses, and the phenomenon of hollow villages is widespread. (3) Due to the small-scale farming model of household contract responsibility system currently implemented in rural China, sufficient young labor is needed for cultivation [38]; the lack of sufficient labor has led to a large amount of farmland being abandoned, and the problem of non-graining of farmland is prominent (Figure 3a–c). China's rural homestead system is linked to the registered residence system. Most farmers move to cities, but their registered residence is still in the countryside, and they still enjoy a rural homestead [36]. Therefore, although they do not live in the countryside, their homestead remains. The current homestead system has led to the problem of "reducing residents but not reducing residential land" in Xun County, and is a typical example in rural China [39]. It is necessary to optimize RRAs and reconstruct rural spatial patterns to achieve "smart shrinkage" of RRAs, and guide the effective withdrawal of declining rural residential land. Moreover, there are large-scale flood detention basins within Xun County that pose a significant threat of flooding to RRAs. In 2021, Henan Province in central China suffered the "7·20" heavy rainstorm. A huge amount of rainwater gathered in the flood detention basin of Xun County, flooding a large area of RRAs and causing significant property losses (Figure 3d), which caused widespread concern [40]. Optimizing RRAs by considering spatial policy regulations for flood detention areas can reduce the risk

of flooding and enhance their resilience to natural disasters, and would have implications for optimizing RRAs in other types of ecologically fragile areas.



Figure 3. Rural decline and floods in Xun County.

3. Data Source and Methods

3.1. Data Source

Geographic vector data and socio-economic statistics were used in this study. The patches of RRAs come from the annual change data of the Third National Land Survey in Xun County in 2021, which was provided by the Natural Resources and Planning Department of Xun County. The Third National Land Survey was organized by the Chinese government and completed in 2019. It utilized high-precision aerospace imagery and advanced unmanned aerial vehicle (UAV) on-site measurement technology, with a spatial resolution of over 1 m. The imagery can reflect natural resource data such as residential areas, roads, and water systems in high definition. It is the official land use data used by the Chinese government and is updated annually to ensure its timeliness. Other geographic vector data such as land types, roads, and water systems were extracted from the Third National Land Survey data. The spatial control data for basic farmland, urban development boundaries, and flood detention basin were also provided by the Natural Resources and Planning Department of Xun County. DEM was obtained through application from the Geographic Information Monitoring Cloud Platform (http://www.dsac.cn/ (accessed on 15 August 2024)).

The socio-economic statistics of population and GDP were sourced from the Xun County Statistical Yearbook in 2022.

3.2. Method

3.2.1. Analytical Hierarchy Process

The Analytic Hierarchy Process (AHP) is a simple, flexible, and practical multi-objective decision-making method proposed by American operations researcher Thomas Saaty in the 1970s, which can quantitatively process qualitative problems using hierarchical weight decision analysis [41]. AHP treats a complex multi-objective decision-making problem as a system, decomposing the objectives into multiple objectives or criteria, and further decomposing them into several levels of multiple indicators. Through qualitative indicator fuzzy quantification methods, the single weight and total weight order of each level are calculated, which serves as a systematic method for optimizing decision-making with multiple options [42,43]. As the characteristics of practicality, effectiveness, and wide application scope, AHP is widely used in fields such as economic planning and land suitability evaluation [44,45].

After establishing a resistance index system for optimizing RRAs, we used the AHP method to determine the weights of the indicators, then obtained the comprehensive resistance of RRAs, and finally determined the optimization direction of RRAs based on the magnitude of the resistance.

3.2.2. DMCR Model

The MCR model can reflect the cost consumed by an object in a certain process, which generally refers to the process from the starting point to the endpoint [46]. The resistance surface usually constructed by the MCR model is the natural attribute resistance of the environment in which the research object is located, such as elevation, location, and land type [47,48]. Considering the special control requirements of the flood detention basin with Xun County, this study incorporates a policy regulation resistance system while considering the natural attribute resistance system, and establishes a DMCR model, which can better reflect the types and intensity of resistance faced by RRAs in Xun County. The specific calculation formula is as follows:

$$VMCR = w_D * f_{min} \sum_{j=n}^{i=m} (D_{ij} + R_i) + w_s * f_{min} \sum_{j=n}^{i=m} (S_{ij} + T_i) \quad (1)$$

where $VMCR$ represents the minimum cumulative resistance value from source j to a certain point, f is a function that represents $VMCR$ in direct proportion to $D_{ij} \times R_i$ and $S_{ij} \times T_i$, D_{ij} and S_{ij} respectively represent the distance need to cross from source j to a certain point in space of the natural attribute resistance system and the spatial control resistance system, R_i and T_i respectively represent the resistance along any direction in space from the source i of the natural attribute resistance system and the policy regulation resistance system, respectively, and w_D and w_S represent the weights of the natural attribute resistance system and the policy regulation resistance system, respectively.

(1) Natural attribute resistance system

We have selected 9 indicators from terrain resistance, location resistance, and production resistance to establish a natural attribute resistance system for optimizing RRAs. Terrain resistance includes elevation (X1), slope (X2), and aspect (X3), location resistance includes distance to town (X4), distance to road (X5), distance to railway (X6), and distance to water (X7), and production resistance includes cultivation distance (X8) and land use type (X9) (Table 1). Referring to relevant research [1,26] and based on the actual natural attributes of Xun County, we assigned resistance values ranging from 1 to 5 to the suitability of each natural resistance index for the optimization of RRAs. Among them, the distance to the railway is a negative indicator because farmers rely less on railways for their daily lives and production, and railways may block the connection between villages and generate noise. The cultivation distance is measured by the distance from RRAs to the nearest cultivated land.

Table 1. Natural attribute resistance system.

Primary Indicators	Secondary Indicators	Weights	Resistance Value				
			1	2	3	4	5
Terrain resistance	Elevation (m)	0.06	≤40	(40, 75]	(75, 125]	(125, 175]	>175
	Slop (°)	0.12	≤2	(2, 5]	(5, 15]	(15, 25]	>25
	Aspect	0.08	Flat	South, Southeast, Southwest	East, West	Northeast, Northwest	North
Location resistance	Distance to town (m)	0.14	≤1000	(1000, 2000]	(2000, 3000]	(3000, 4000]	>4000
	Distance to road (m)	0.14	≤500	(500, 1000]	(1000, 1500]	(1500, 2000]	>2000
	Distance to railway (m)	0.08	>4000	(3000, 4000]	(2000, 3000]	(1000, 2000]	≤1000
	Distance to water (m)	0.11	≤200	(200, 500]	(500, 1000]	(1000, 1500]	>1500
Production resistance	Cultivation distance (m)	0.12	≤100	(100, 200]	(200, 300]	(300, 400]	>400
	Land use type	0.15	RRAs	Garden, forest	Unused land	Cultivated land	Waters, Others

The lower the value of the natural attribute resistance index, the more suitable it is for rural residential construction. Conversely, if the value is higher, the greater the resistance to rural residential construction. We assigned values and mapped the resistance of natural attributes in Xun County based on the index system, and obtained the resistance surface of natural attributes in RRAs (Figure 4).

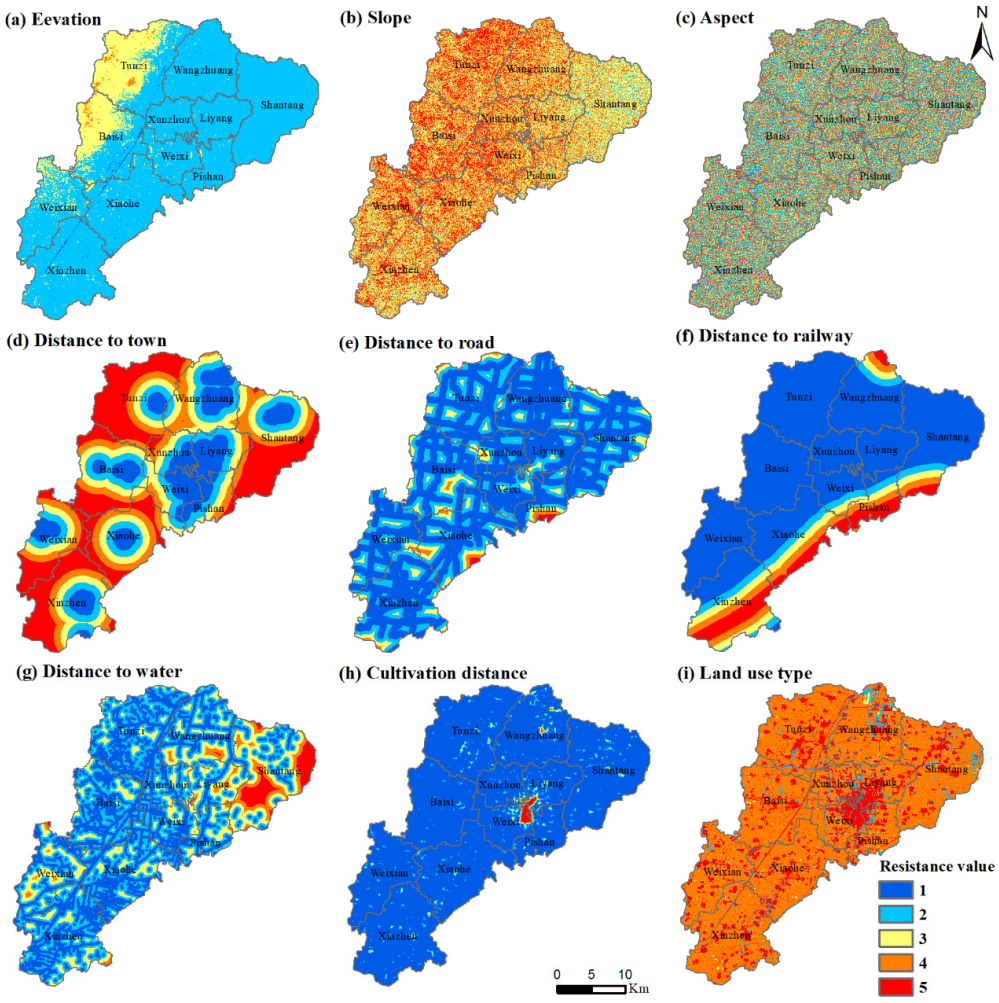


Figure 4. Distribution of natural attribute resistance surface in RRAs.

(2) Policy regulation resistance system

The optimization of RRAs should consider the suitability of natural attributes to achieve the goal of favorable production and convenient living, as well as the goal of standardized layout and efficient utilization through regional regulation policies. There are prominent problems with the scattered layout, extensive utilization, and conflicts with the spatial control system of national land planning of RRAs in Xun County. In order to measure these issues, we established a policy regulation resistance system for optimizing RRAs from the perspectives of their own shape, utilization efficiency, and planning policies. The policy regulation resistance system includes six indicators of internal resistance and policy resistance (Table 2). Internal resistance considered the patch morphology and intensive utilization of RRAs, and three indicators were selected: patch shape index (Y1), patch size (Y2), and per capita RRAs (Y3). Among them, although the patch shape index and patch size are the inherent shape characteristics of RRAs, they can reflect whether the layout of RRAs is compact and efficiently utilized. They are important criteria for Chinese land management departments to measure whether RRAs are scattered and extensively utilized, and therefore were included in the policy resistance system. The specific calculation formula and meaning are as follows:

Table 2. Policy regulation resistance system.

Primary Indicators	Secondary Indicators	Weights	Resistance Value				
			1	2	3	4	5
Internal resistance	Patch shape index	0.08	(0.9, 1.1]	≤0.9, (1.1, 2.0]	(2.0, 3.0]	(3.0, 4.0]	>4.0
	Patch size (hm)	0.12	>0.14	(0.1, 0.14]	(0.07, 0.1]	(0.037, 0.07]	<0.037
	Per capita RRAs (m^2)	0.20	≤230	(230, 240]	(240, 250]	(250, 300]	>300
Policy resistance	Permanent basic farmland	0.15	Outside				Inside
	Urban development boundaries	0.15	Outside				Inside
	Flood detention basin boundaries	0.30	Outside				Inside

① Patch shape index

The patch shape index is calculated as the ratio of the circumference and four times the root of area of patches. If the value of patch shape index is closer to 1, the patch is closer to be a square and more regular, and the resistance to optimizing RRAs is smaller. Conversely, the more the patch shape index deviates from 1, the greater the resistance value.

$$PSI = P/\left(4\sqrt{A}\right) \quad (2)$$

where PSI represents the patch shape index, P represents the circumference of the patch, and A represents the area of the patch.

② Patch size

The larger the scale of RRAs, the easier it is to access basic infrastructure for daily life and production, and the smaller the resistance to optimizing RRAs. On the contrary, the smaller the scale, the greater the resistance. The scale of RRAs is represented by the area of each patch.

③ Per capita RRAs

Per capita land area is the most direct indicator for measuring whether land use is intensive [49,50]. The larger the per capita RRAs, the less intensive the utilization of RRAs, and the greater the resistance to optimizing RRAs. On the contrary, the smaller the per capita RRAs, the less resistance there is to optimizing RRAs.

$$PCRRAs = RA/RP \quad (3)$$

where *PCRRAs* represents per capita RRAs, *RA* represents the area of RRAs, and *RP* represents the rural population.

The policy resistance mainly considered the "Three lines" strategy, which is the principal land spatial control policy implemented by China's territorial spatial planning [51]. The "Three lines" refer to the ecological protection red line that strictly implements ecological conservation, the permanent basic farmland that maintains stable quantity and quality of arable land, and the urban development boundary that controls urban expansion. Due to the lack of ecological protection red lines within Xun County, policy regulation resistance only selected the indicators of permanent basic farmland (Y4) and urban development boundaries (Y5). Considering that Xun County is an important flood detention basin in the Haihe River Basin, this study also selected the boundary of the flood detention basin (Y6) as a policy resistance indicator. Complying with policy regulation requirements, it is not suitable to expand RRAs within the boundaries of permanent basic farmland, urban development, and flood storage basin. Therefore, we set the maximum resistance value of 5 within the boundaries of permanent basic farmland, urban development, and flood storage areas, and set the resistance value of 1 outside the boundaries.

The calculation units for patch shape index and patch size are rural residential patches, and the smallest statistical unit for rural population acquisition is townships; the resistance surface units for these three indicators are the rural residential patch and the 11 townships, respectively. The resistance surface of policy resistance indicators covers the entire region (Figure 5).

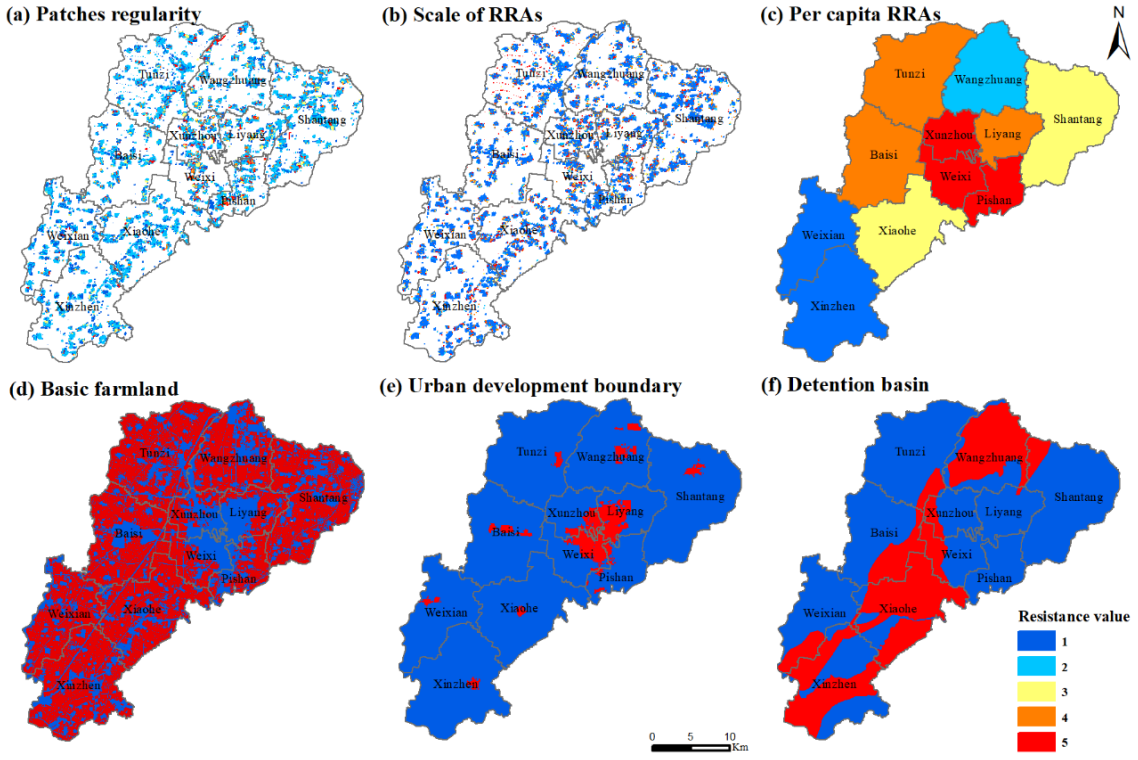


Figure 5. Distribution of policy regulation resistance surface in RRAs.

(3) Comprehensive resistance analysis

The hierarchical analysis method based on expert scoring was used to assess the importance of the natural attribute resistance system and policy regulation resistance system in optimizing RRAs. The comprehensive weights of the natural attribute resistance system and policy regulation resistance system were obtained (Table 3), and then the comprehensive resistance of optimizing RRAs in Xun County was analyzed to determine the final resistance value of each RRA.

Table 3. The weight of two resistance systems.

Resistances	Weights
Natural attribute resistance system	0.4
Policy regulation resistance system	0.6

4. Results

4.1. Scale and Spatial Pattern of Rural Residential Areas

In 2021, there were 24499 patches of RRAs in Xun County, with a total area of 10188.29 ha and an average patch area of 0.42 ha. We classified the RRAs into four types based on patch size: large RRAs (>1.33 ha), medium RRAs ((0.42, 1.33]), small RRAs ((0.10, 0.42]), and micro RRAs ($\leq$0.10) (Table 4). In terms of the number of patches, the maximum number of micro RRAs reached 11709, accounting for 47.79% of the total number of patches, while the minimum number of large RRAs was only 2031, accounting for 8.29% of the total number of patches. In terms of the area of patches, the large RRAs have the largest area at 5032.52 ha, accounting for 49.40% of the total area, while the micro RRAs have the smallest area at only 547.04 ha, accounting for 5.37% of the total area. Overall, the patch area of RRAs in Xun County is generally small, with nearly half of them being micro residential areas with an area of no more than 0.1 ha. Too many micro RRAs make it difficult to lay out public infrastructure and improve land use intensity.

Table 4. Scale and proportion of RRAs.

Types	Number of Patches	Quantity Proportion (%)	Area (ha)	Proportion of Area (%)
Large RRAs	2031	8.29	5032.52	49.40
Medium RRAs	4177	17.05	3240.40	31.81
Small RRAs	6582	26.87	1368.33	13.43
Micro RRAs	11,709	47.79	547.04	5.37

The distribution of RRAs in Xun County is relatively scattered, with more RRAs in the north than in the south (Figure 6). The RRAs around the urban area are relatively concentrated, the towns with more RRAs are Shantang, Tunzi, and Wangzhuang. Large RRAs are mainly distributed in a strip along main roads, while medium and small RRAs are mainly distributed around large RRAs, and micro RRAs are mostly sporadically distributed. Overall, the spatial agglomeration of RRAs in Xun County is relatively low, manifested by fewer large-scale patches and too many micro and scattered RRAs. Moreover, there is a significant spatial conflict between the distribution of RRAs and policy regulations. Among them, 2406.04 ha of RRAs are located within the flood detention basin, 766.19 ha are located within the urban development boundary, and even 17.72 ha of RRAs occupy basic farmland. These spatial conflicts may pose significant risk of flood disasters to RRAs, damage farmland protection, and constrain urban development.

4.2. Resistance in Rural Residential Areas

4.2.1. Natural Attribute Resistance

Natural attribute resistance is a comprehensive evaluation of the resistance to the optimization of RRAs based on the conditions of terrain, location, and production. According to the results, the range of natural attribute resistance values in Xun County is 1.72 to 3.97 (Figure 7). The areas with relatively low values of natural attributes resistance, which are conducive to the expansion of RRAs, are mainly distributed in the built-up areas of Wangzhuang, Shantang, and Baisi. These areas are mainly flat in terrain and close to towns and main roads. The areas with high values of natural attributes resistance, which are not suitable for RRAs expansion, are mainly distributed in the northwest and eastern borders. The high-value areas in the northwest are due to their high and uneven terrain, while the

high-value areas in the eastern borders are mainly due to their long distance from water sources and proximity to railways, which are not conducive to daily production and life.

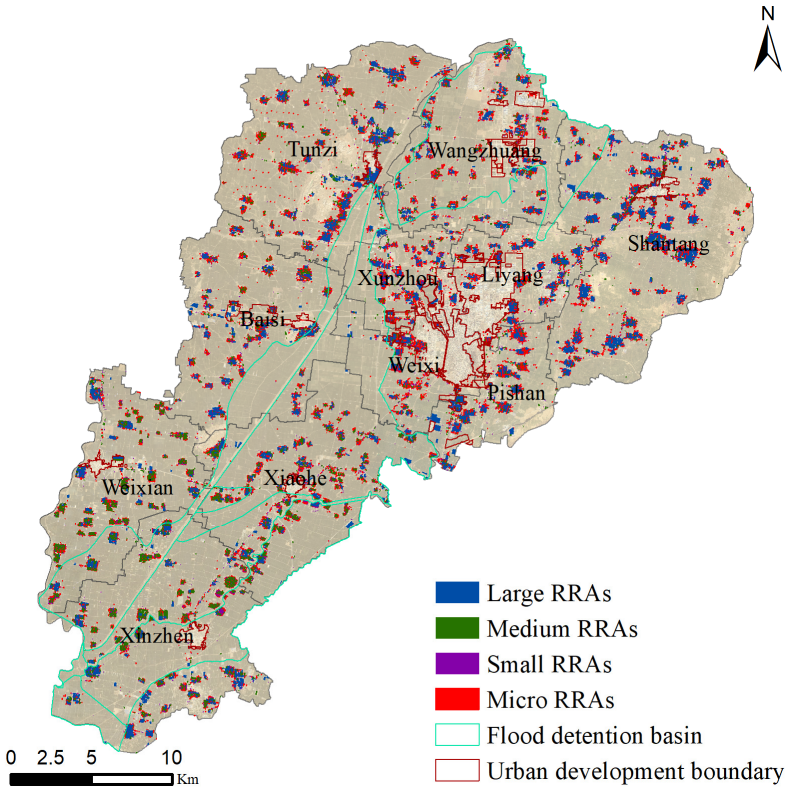


Figure 6. Types and distribution of RRAs in Xun County.

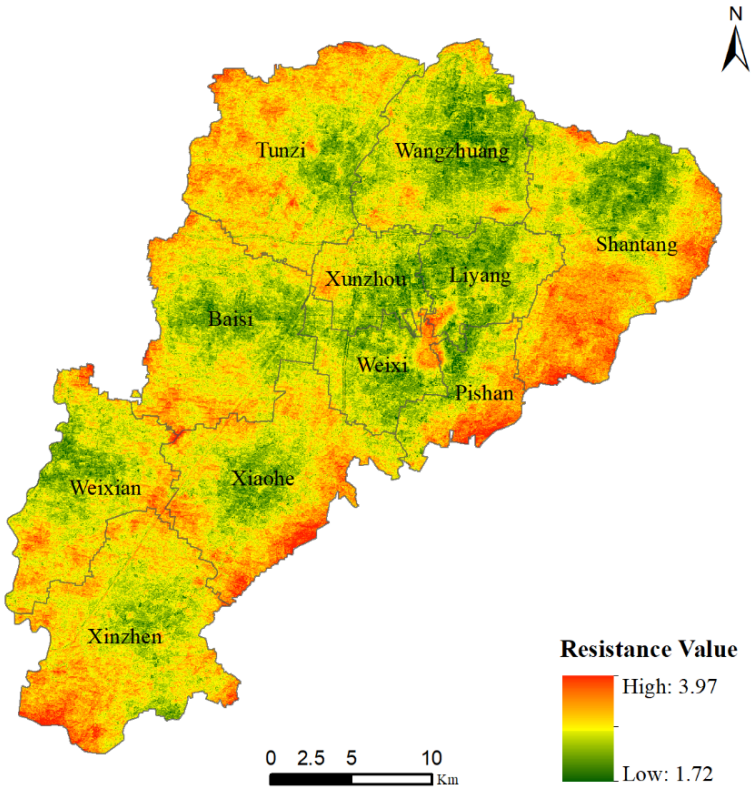


Figure 7. Distribution of natural attribute resistance for optimizing RRAs.

4.2.2. Policy Regulation Resistance

The evaluation objects of the two indicators of patch shape index and patch size in the policy regulation resistance system are only RRAs patches. Therefore, after comprehensive evaluation of the policy regulation resistance, only RRAs patches have the policy regulation resistance value. The range of policy regulation resistance values for RRAs patches in Xun County is 1.00 to 3.96 (Figure 8). The RRAs with high value of policy regulation resistance, which require consolidation and relocation, are mainly concentrated in Xiaohe in the south and Wangzhuang in the north. These high-value patches in Xiaohe are mainly located in flood detention basin with large per capita RRAs, while those in Wangzhuang are mainly located in flood detention basin with low patch shape index. The RRAs with low resistance values, which should be preserved or improved, are mainly located in Weixian, Tunzi, and Shantang. These low-value patches are located outside the spatial control zones such as flood detention basin, basic farmland, and urban development boundaries, and the per capita RRAs are relatively low.

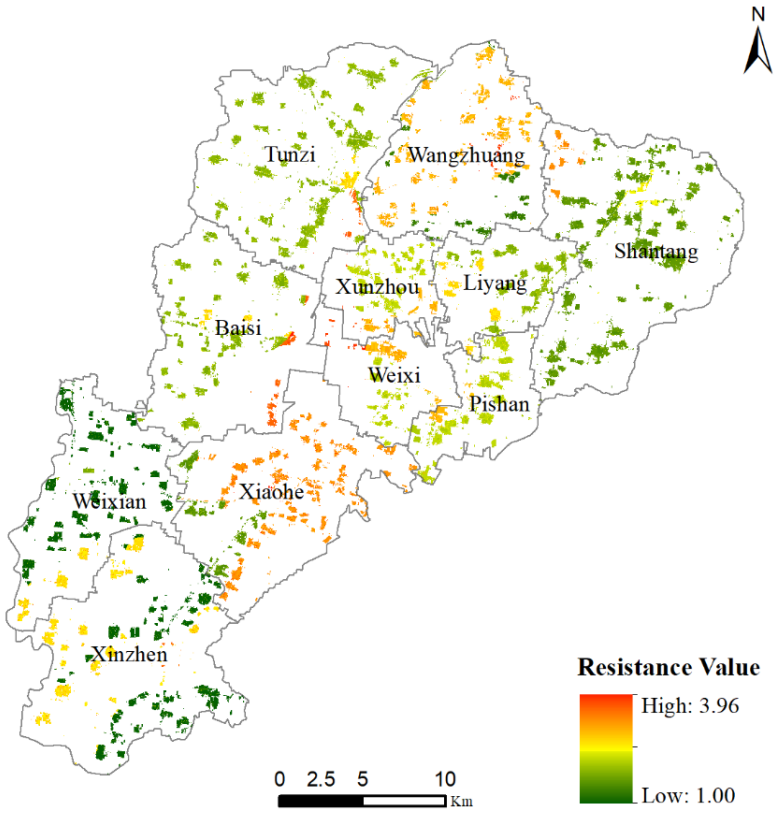


Figure 8. Distribution of policy regulation resistance for optimizing RRAs.

4.2.3. Comprehensive Resistance Analysis

We used policy regulation to correct the resistance based on natural attribute resistance. The changes in natural attribute resistance after correction are shown in Figure 9. The resistance values of RRAs in Xun County have mostly decreased after correction, but there are significant spatial differences. The resistance value of RRAs in the peripheral border areas of Xun County decreased, indicating that these areas are more suitable for rural settlement construction. The reduction in resistance values of RRAs in the central region is significantly lower than that in the peripheral areas, and even some residential areas have seen an increase in resistance values. This indicates that the central region is facing greater resistance to the construction of rural residential areas after considering policy regulation factors. The changes in the optimized resistance values of RRAs in Xun County after correcting the natural attribute resistance with policy regulation resistance indicate

that the central region faces greater resistance compared to the peripheral regions. This spatial characteristic of the changes is in line with the control requirements of the Xun County flood detention basin. Therefore, after comprehensively considering the resistance of natural attributes and policy regulation, the optimization of RRAs in Xun County can provide better guidance for the optimization of RRAs in flood detention basin.

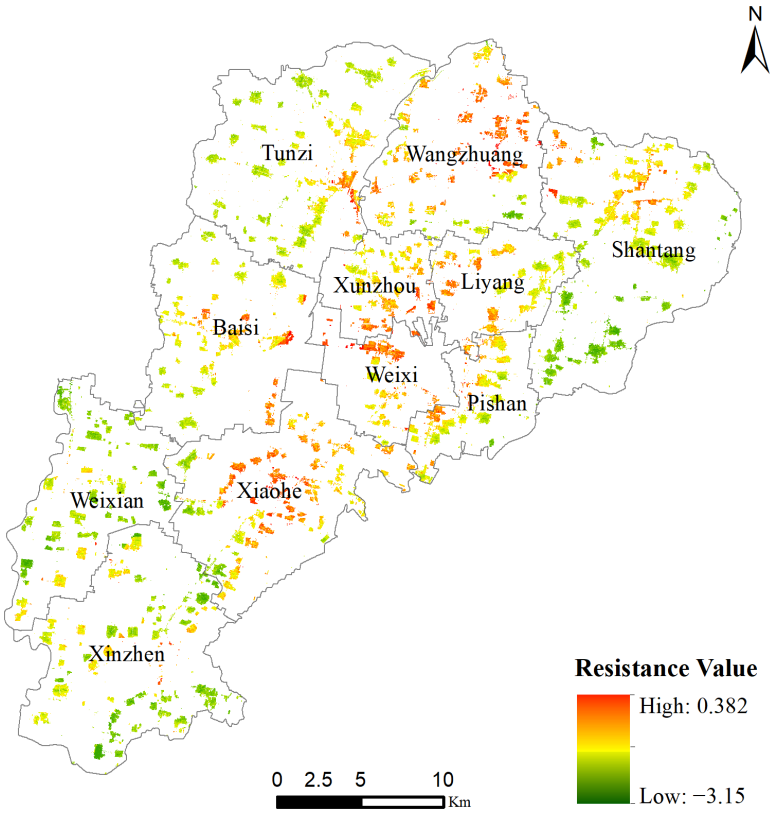


Figure 9. Changes in natural attribute resistance values after policy regulation resistance correction.

After weighting and summing the natural attribute resistance and policy regulation resistance of RRAs, their comprehensive resistance was obtained. The range of comprehensive resistance values for optimizing RRAs is 0.60 to 2.38 (Figure 10). The RRAs with high comprehensive resistance values, which means that these RRAs face unsuitable natural attributes or high policy regulation pressure, are mainly distributed in the central areas of Xiaohe, urban areas, and Wangzhuang. The RRAs with relatively low comprehensive resistance value, which means that these RRAs face less natural and policy pressure during the expansion of RRAs, mainly distributed in eastern or western peripheral towns such as Shantang, Weixian, and Tunzi.

4.3. Optimization of RRAs

4.3.1. Optimization Direction for RRAs

The optimization direction of rural residential areas was determined by the magnitude of the comprehensive resistance value. ArcGIS 10.8 software's natural discontinuity method was used to classify the comprehensive resistance values of RRAs into three types: high resistance (>1.27), medium resistance ((0.89, 1.27]), and low resistance ($\leq$0.89). Their optimization directions were determined to be annexation or evacuation (AE), consolidation and improvement (CI), and clustering and upgrading (CU), respectively (Table 5). The area of RRAs in the optimization direction of AE is 3175.22 ha, accounting for 31.17%; the area of RRAs in the optimization direction of CI is 4902.37 ha, accounting for 48.12%; the area of RRAs in the optimization direction of CU is 2110.70 ha, accounting for 20.72%.

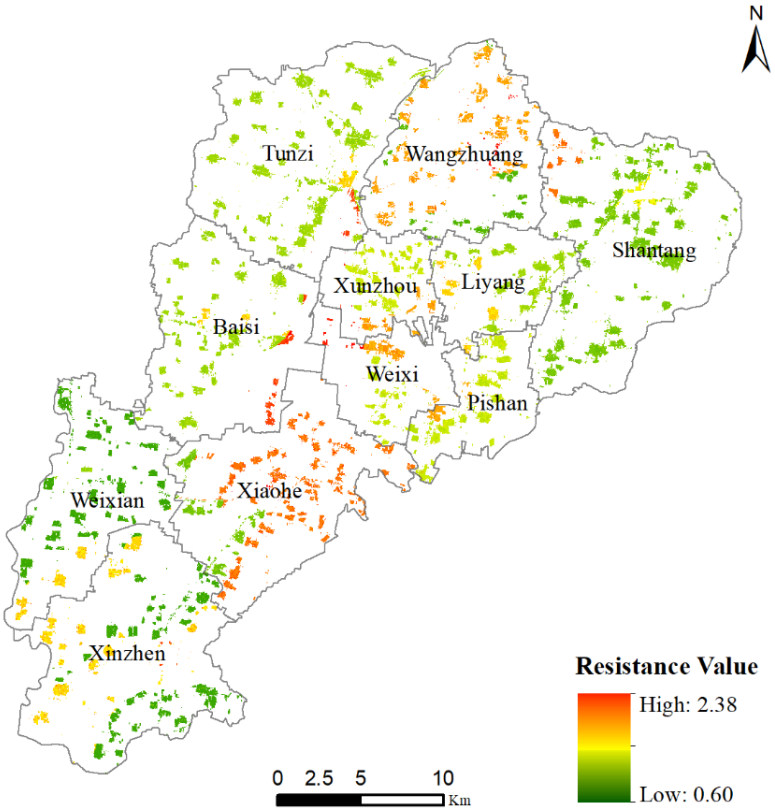


Figure 10. Distribution of comprehensive resistance for optimizing RRAs.

Table 5. Optimization direction, resistance type, and area.

Optimization Direction	Resistance Type	Range of Resistance Values	Area (ha)	Ratio (%)
CU	Low resistance	≤0.89	2110.70	20.72
CI	Medium resistance	(0.89, 1.27]	4902.37	48.12
AE	High resistance	>1.27	3175.22	31.17

The RRAs with optimization direction of AE mainly concentrated in the central areas of Xiaohe, Wangzhuang, urban areas, and the southern areas of Xinzhen. The RRAs with optimization direction of CI mainly distributed in the central and northern areas of Baisi, Tunzi, urban areas, and Shantang. The RRAs with optimization direction of CU is mainly concentrated in the southern towns of Weixian and Xinzhen (Figure 11).

Only five towns (Shantang, Xinzhen, Xiaohe, Weixian, and Wangzhuang) have RRAs in the optimization direction of CU. Among them, Weixian and Xinzhen have the largest areas of 745.56 and 743.49 ha, with RRAs in this direction accounting for 79.17% and 59.72% of their total RRAs, respectively. These two towns are key areas for the future aggregation and expansion of RRAs, and efforts should be made to improve the living environment and enhance the service of rural public infrastructure. The RRAs in the optimization direction of CI in Shantang and Tunzi have the largest areas, reaching 1628.28 and 1152.99 ha, respectively. The proportion of RRAs in this direction also reached 75.75% and 89.18%, respectively. The proportion of RRAs in the direction of CI in Xunzhou, Liyang, Pishan, and Baisi also exceeded 70%. The areas of RRAs in the optimization direction of AE in Xiaohe and Wangzhuang are the largest, reaching 852.21 and 668.88 ha, with proportions of 73.68% and 74.44%, respectively. The future relocation and reduction of RRAs should focus on these two towns. The proportion of RRAs in the direction of AE in towns such as Weixi and Xinzhen is also relatively high (Figure 12).

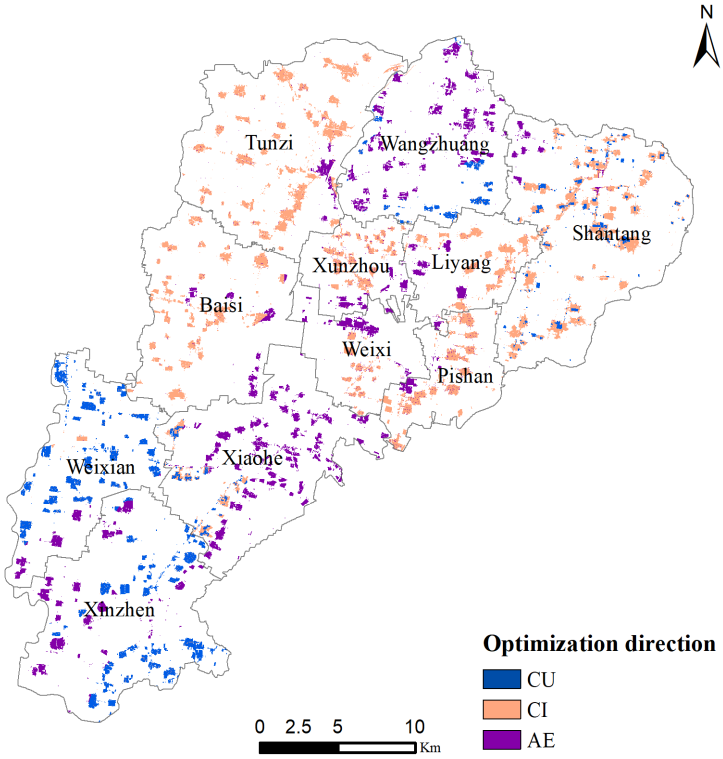


Figure 11. Distribution of optimization directions for RRAs.

4.3.2. Optimization Strategy for RRAs

Compared with developed countries, China's urbanization rate is still relatively low, and China will continue to be in a stage of rapid urbanization for a long time. The common phenomenon in rural China in the future will continue to be the massive loss of residents and the disappearance of villages. Therefore, under the ultimate goal of efficient resource utilization and smart reduction of RRAs, cleaning up and rectifying idle and abandoned homesteads and improving preserved RRAs are important tasks for optimizing RRAs. Considering the fragile ecological environment of the large flood detention basin in Xun County, we propose corresponding optimization strategies for RRAs in different optimization directions.

(1) The optimization strategies in the direction of CU.

Scientifically formulating village planning to optimize layout of RRAs and improve their agglomeration. Pay attention to the matching between internal factor supply and the actual needs of villagers, upgrade existing public service facilities, and increase ecological green spaces to enhance residential suitability. These RRAs can allow for appropriate outward expansion to accommodate residents from relocated villages and support their development into regional core villages. New RRAs can only be built on higher terrain, and existing RRAs need to upgrade their embankments to improve their flood response capabilities.

(2) The optimization strategies in the direction of CI.

The scale of RRAs in this direction is prohibited from expanding, and their area should be appropriately reduced through land consolidation. The specific optimization strategies are to clean and reclaim idle and abandoned homesteads, improve the environment and facilities of well-developed residential areas, guide various production resources to flow towards advantageous areas, and ultimately achieve smart reduction of RRAs. Strengthen the construction of embankment projects for RRAs located in flood detention basin, and raise the existing village embankments to improve their ability to cope with flood disasters.

(3) The optimization strategies in the direction of AE.

The optimization strategy for RRAs in this direction should be gradually demolished. The RRAs located in urban areas belong to the suburban integration type, while the rest belong to the revocation type. Suburban integrated RRAs are located on the edge of the main urban area and are areas for future urban expansion. These RRAs will gradually integrate into the city and become a part of the urban area. The layout of urban industrial land and the proportion of green space should be increased, and the extensive rural land use should be replaced by highly intensive urban land use. The revoked RRAs are far away from the urban area and their development is subject to significant natural and policy constraints. This type of RRAs is prohibited from being newly built, and should be demolished after their entire population migrates out. Residents of RRAs located in policy regulation areas such as flood detention basin will be systematically relocated to surrounding the RRAs in the direction of CU.

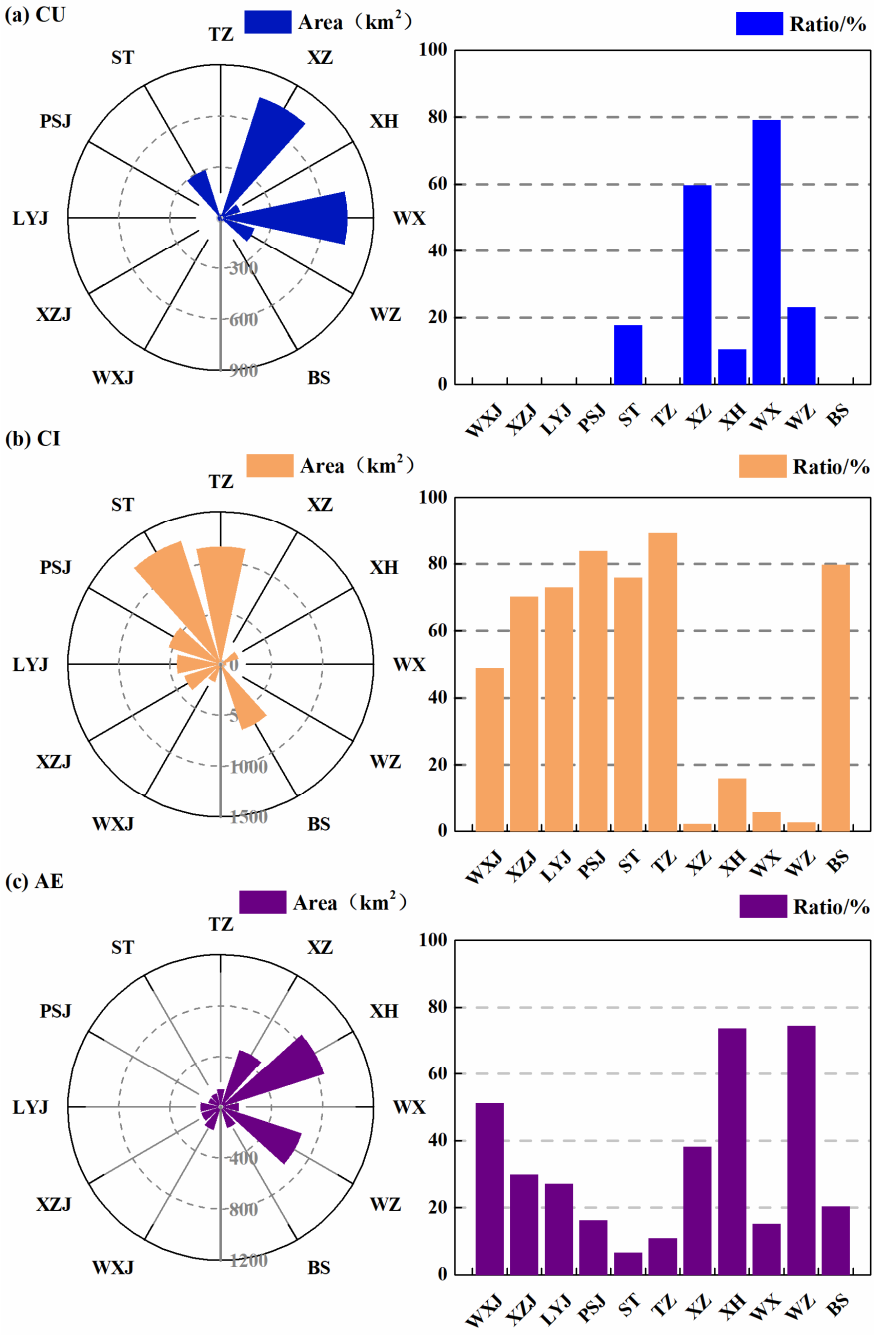


Figure 12. Area and ratio of optimization directions for RRAs in townships.

5. Discussion

5.1. Resilience of Rural Sustainable Development

Rural areas in China have long dominated the population, economy, and socio-cultural, and have continuously provided material and labor support for urban development [52,53]. However, the development of RRAs in China has long lacked planning guidance, resulting in arbitrary layout and blind expansion [54]. This phenomenon has triggered a series of resource and environmental issues, such as a large amount of arable land being occupied, ecological space being destroyed, and residential areas expanded to riverbanks and mountain slopes [6]. In 2021, the area of RRAs in Xun County located within the flood detention basin was 2406.04 ha, the area within the urban development boundary was 766.19 ha, and 17.72 ha were located within basic farmland. Meanwhile, as the rural population continues to decrease, the original rural ecosystem has been gradually collapsing. Rural areas are constantly facing the impact of sudden natural disasters, public health events, cultural erosion, and social interference. The increasing uncertainty of rural development seriously affects the sustainable development of rural areas. Rural areas can reconstruct their internal structure and functions through optimizing RRAs, enhancing the resilience of socio-economic development and natural disaster.

Due to the large area of flood detention basin within Xun County, the biggest natural disaster it faces is flooding. Therefore, enhancing resilience to floods is an important task for optimizing rural settlements. Organized migration of residents in the RRAs in the direction of AE gradually achieves the complete demolition of RRAs. For RRAs that cannot be demolished in the direction of CI, it is necessary to strengthen the construction of embankment projects and build new embankments around densely populated and high terrain villages to prevent floods. New residential areas for villages in the direction of CU must be built in areas with higher terrain and strengthened drainage system construction. Moreover, in the process of optimizing RRAs, comprehensive river dredging, embankment reinforcement, and riverbank maintenance must be carried out to improve the flood discharge capacity of the river, which will significantly enhance the resilience of rural areas to flood disasters. The Chinese government implemented a series of urban–rural land regulation policies, such as linking the increase and decrease of urban–rural construction land [55]. The area of RRAs in the direction of AE in Xun County is 3175.22 ha, accounting for 31.17% of the total RRAs. This means that there is a reduction of 3175.22 ha in RRAs in Xun County. These reduced rural settlements can be used to trade construction land indicators with cities, and the funds obtained from the trade can be used to upgrade rural infrastructure and restore ecosystems. It is conducive to revitalizing rural culture and improving rural living conditions, thereby enhancing the resilience of rural socio-economic development.

5.2. Comparison with Previous Studies

Optimizing the spatial pattern of RRAs is a long-standing hot topic of concern in disciplines such as geography, sociology, and management. Numerous scholars have conducted extensive research on the potential evaluation [56], impact mechanism [57], and optimization mode of RRAs in China [36], with research objects mostly focused on typical plain or mountainous areas. The existing research mainly considers the natural attributes of rural settlements such as terrain, slope, location, and land use, with little integration of local control policies. The results are often universal and difficult to provide targeted optimization guidance for RRAs with local characteristics. Moreover, with the frequent occurrence of global natural disasters posing greater challenges to the construction of rural settlements, research on optimizing RRAs in ecologically fragile areas such as flood detention basins that are greatly affected by natural disasters is relatively scarce. Compared with previous studies, the main contributions of this research are as follows: (1) This is the first time that attention has been paid to the optimization of RRAs in flood detention basins. With global climate change, various natural disasters are occurring frequently. The destructive effects of drought or floods on rural life cannot be ignored. By conducting targeted research on optimizing RRAs in flood detention basins, practical reference can

be provided for the spatial governance of rural settlements in various ecologically fragile areas under the background of global climate anomalies. (2) Spatial policy regulations incorporated into the optimization evaluation system of RRAs. The Chinese government has established various spatial policy regulations for land use in various development plans. These spatial policy regulations are the basis for the Chinese government's territorial spatial governance and have an important impact on the layout of RRAs. Previous studies have rarely considered these policies due to difficulties in obtaining data. This study incorporated spatial policy regulations such as flood detention basins and urban development boundaries into the optimization evaluation system for RRAs, and assigned them high weights, which makes the evaluation results more practical and instructive.

5.3. Recommendations and Future Work

We integrated the dual factors of natural attributes and policy regulation to evaluate the minimum cumulative resistance for optimizing RRAs in flood detention basin and providing direction and strategies. This study expands the research object and enriches the evaluation system of RRAs optimization. However, there are also some limitations in this study that require further in-depth research. Firstly, the optimization of RRAs is a major project involving multi-party games and concerns the vital interests of rural residents. The demands of various stakeholders and farmers should be taken seriously when determining the direction and strategy of optimization. Secondly, the development of RRAs is a dynamic process, and one type of RRAs may naturally transform into another at a certain time. Therefore, how to scientifically understand the spatiotemporal evolution of RRAs and predict their transformation paths to help optimize RRAs needs further research.

6. Conclusions

This study focused on flood detention basins, established a DMCR model with dual factors of natural attributes and policy regulation, evaluated resistance types, and determined optimization directions accordingly, which helps to enhance the intensive utilization of RRAs and their resilience to natural disasters, providing practical references for optimizing RRAs in other typical ecologically fragile areas. The main conclusions are as follows:

(1) The RRAs in Xun County are relatively scattered. The number of patches in large RRAs, which account for 49.40% of the total area of RRAs, only accounts for 8.29% of the total patches, while the number of patches in micro RRAs, which account for only 5.37% of the total area of RRAs, accounts for 47.79% of the total patches.

(2) The RRAs with higher resistance values in Xun County are mainly distributed in the central and northern towns, while the RRAs with lower resistance values are mainly in the peripheral towns in the west and east. The factors that have a significant impact on resistance include policy resistance, location resistance, production resistance, and terrain resistance.

(3) The optimization of RRAs is divided into three directions based on the resistance value: annexation or evacuation, consolidation and improvement, and clustering and upgrading. The proportion of RRAs in the direction of consolidation and improvement is the highest at 48.12%, mainly located in Shantang, Tunzi, and urban areas; followed by annexation or evacuation at 31.17%, mainly located in Xiaohe and Wangzhuang; the area in the direction of clustering and upgrading with the lowest resistance is the smallest at 20.72%, mainly located in the southern areas of Weixian and Xinzhen.

(4) Targeted strategies have been proposed for different optimization directions. RRAs in the direction of CU should improve their public infrastructure and living conditions, which can be appropriately expanded to accommodate relocated residents; RRAs in the direction of CI are prohibited from expanding, and scattered and idle homesteads are eliminated through comprehensive land consolidation; and RRAs in the direction of AE will be completely eliminated, while those in the suburbs will gradually integrate into the urban area, and those in the outer suburbs will be fully demolished after the population migrates or completely lost.

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