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Suitability Analysis of Water Cultural Heritage Structures in Beijing Based on Analytic Hierarchy Process and Geographic Information Systems

Yan Li [1], Changzheng Wang [1], Feiyang Xue [2], Kunpeng Zhou [1] and Chong-Chen Wang [1,*]

1 Beijing Key Laboratory of Functional Materials for Building Structure and Environment Remediation, Beijing University of Civil Engineering and Architecture, Beijing 100044, China
2 School of Architecture and Urban Planning, Beijing University of Civil Engineering and Architecture, Beijing 100044, China
* Correspondence: wangchongchen@bucea.edu.cn

Abstract: As significant physical carriers of hydraulic science and technology, water cultural heritage (WCH) structures might exert positive effects on the economy, society, and environment. However, it is challenging to develop a scientific conservation plan due to the lack of comprehensive cognition and value assessment criteria for the vast majority of WCH structures. In this study, the analytic hierarchy process (AHP) and geographic information systems (GIS) were introduced to develop a multidimensional evaluation system for WCH in Beijing based on the suitability perspective. This approach proposes a strategy covering macro, meso, and micro levels based on three aspects: heritage value, spatial distribution, and environmental resistance. The findings indicated that there are significant differences in values among the nine heritage categories, and royal gardens and rivers were suggested for greater emphasis on protection. Besides, the distribution of WCH structures is clustered, which can be categorized into four distinct agglomerative zones. Most of the heritage sites are found on built-up land with low elevation and gentle slopes, resulting in high environmental suitability. Lastly, we proposed a framework for conservation with "one centre, two wings, one area, and a multi-node" to facilitate the development of effective policies by decision-makers.

Keywords: water cultural heritage; suitability analysis; geographic information systems; analytic hierarchy process; minimum cumulative resistance model

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1. Introduction

The development of engineering and institutional systems for water supply, irrigation, sewage, flood control, and navigation has been inextricably linked to the growth of large cities around the world [1], creating a wide variety of water-related heritages. In older towns, ancient water infrastructures have served as critical mediators for the security of the municipal water supply.

With a range of water resources and ecological challenges, water-related heritage research is becoming of increasing interest. At the Third World Water Forum, the United Nations Educational, Scientific and Cultural Organization (UNESCO) and the International Hydrographic Organization (IHO) launched the theme "*Water and Cultural Diversity*" under the direction of the International Hydrological Programme (IHP) [2]. The challenge and potential solutions were revealed in a discussion on water and heritage initiated by the International Council on Monuments and Sites (ICOMOS) [3]. However, the international academic field has yet to develop a unified terminology to define water-related heritage. Two types of heritages fall into this category, namely World Heritage Irrigation Structures (WHIS) and World Water System Heritage (WWSH) [4]. They are considered essential tools for understanding the relationship between humans and water resources and are worthy of preservation. Nevertheless, they have generally been neglected in territorial management and protective actions [5].

The concept of "water cultural heritage (WCH)" emerged in China during the 1980s. According to UNESCO's Convention Concerning the Protection of the World Cultural and Natural Heritage and Convention for the Safeguarding of the Intangible Cultural Heritage, they were defined as the water-related spiritual and material heritages that humans created during their long-term interaction with water, covering various morphologies such as architectures, sites, landscapes, and folklore [6]. With the entry of Dujiangyan and the Beijing-Hangzhou Grand Canal into the World Heritage List, WCH has become a crucial component of Chinese heritage conservation [7]. As one of the key physical carriers of hydraulic culture, WCH structures comprise extensive and particular knowledge of regional water management and exploitation. Moreover, as unique cultural landscapes and tourism resources, they have played an imperative role in sustainable development [8,9], which also has provided diverse ecological services [10].

A portion of the WCH in China was in danger of extinction because of the country's growing urbanization and weak conservation efforts [11]. The Ministry of Water Resources of the People's Republic of China issued the *Water Culture Construction Planning Outline* to save valuable WCHs. Numerous well-known cities, like Beijing, Chengdu, Zhengzhou, and Shaoxing have conducted wide heritage censuses, in which hundreds and thousands of heritage sites were identified. Beijing's WCH structures are diverse and representative, due to the long history of water-related urban construction [12]. Nevertheless, comprehensive conservation planning and development policies are still not in place because of insufficient protection awareness. It is crucial to introduce a value-oriented assessment system to rationalize the allocation of resources. On this basis, we chose the tangible category of WCH, with a total of 309 items listed in the *Cultural Heritage of Beijing Water* as research objectives [13]. These heritages were divided into nine categories: rivers and lakes (RL), springs and wells (SW), water gates and aqueducts (WA), bridges and dams (BD), gardens and pagodas (GP), temples (TE), stone tablets and carvings (ST), ancient towns and villages (TV), and warehouses and shipwrecks (WS). With a certain degree of consistency and representativeness, they encompass the most common morphologies in all Beijing districts and involve a wide range of functions, materials, and ages. A universal framework for the conservation of WCH can be explored by examining these heritages. We aim to contribute to the development of detailed protection plans and strategies to perpetuate the water culture and water wisdom.

The suitability analysis is a method of evaluation that aims to optimize social, economic, and ecological benefits by superimposing attribute elements [14]. McHarg advocated the use of transparency to overlay information about spatial conditions and features for a particular place, with each layer containing data on a different variable [15]. The optimum area for specific requirements could be identified by overlaying various transparencies. It has been widely used in urban and rural planning, landscape design, and architecture since *Design with Nature* [16] was published. According to specific preferences and activity predictors, suitability analysis can assist in formulating the most scientific conservation intensity and appropriate spatial patterns [17]. For example, suitability analysis enables the evaluation of environmental effects, leading to the study of quantitative data analysis to support decision-making. This considers the unique nature of WCH and contributes to the exploration of possible linear distribution patterns. As a result, it would provide better guidance for conservation efforts.

The analytic hierarchy process (AHP), a multi-criteria analysis approach developed by Saaty, makes it possible to prioritize a series of alternative decisions or to relate standards characterized by qualitative and quantitative evaluations (not directly comparable) combining multidimensional measurement scales to obtain comprehensive priorities [18]. Geographic information systems (GIS) are gaining popularity as an essential tool for environmental analysis and layering spatial information management [19,20]. Based on these two approaches, this study assessed the development suitability of WCH structures from three aspects and established a multi-dimensional (point-to-line-surface) analysis system. First, the comprehensive value of the heritage ontology was evaluated by AHP to classify the conservation priority. Subsequently, GIS was used to analyse spatial distribution characteristics and determine if there were any aggregation areas that could be integrated and planned. Finally, the environmental restrictions on heritage conservation were investigated using the minimum cumulative resistance model (MCRM). This work proposed a framework for conservation at the macro, meso, and micro levels, along with development strategies that can be used by decision-makers to formulate conservation plans. It is of great significance for water ecology improvement and waterfront space enhancement.

2. Data Sources

The data for WCH structures are derived from the *Beijing Water Cultural Heritages* [13] and several field studies. The WCH structures were digitalized based on ArcGIS 10.2, following their scale and form (Figure 1). Most of the heritage structures can roughly be described as point elements, and their geographical locations were indicated by latitude and longitude coordinates. Due to their magnitude, some river heritages were portrayed as line elements.

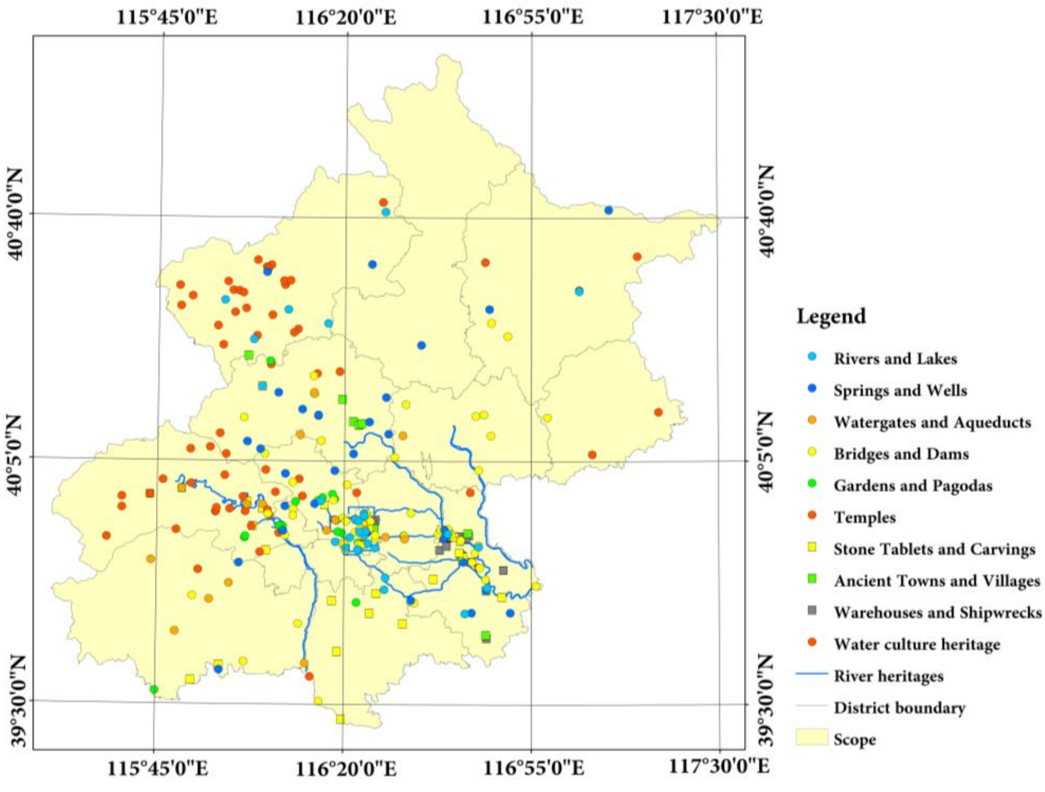

Figure 1. Spatial distribution of Beijing's water cultural heritages.

The geographic environment elements data mainly included Digital elevation model (DEM), Land-use, Administrative divisions, and Water systems. The data was downloaded with the administrative area of Beijing as the boundary, which unified the scale. We reduced the error by making a uniform definition projection to ensure that map data could largely overlap [21]. By comparing the final geodatabase with the standard maps, it was found to be accurate. All data sources are summarized in Table 1.

Table 1. List of data sources used in this study.

Data	Format	Resolution	Time	Source
Digital elevation model (DEM)	Raster	30 m	2020	Geospatial Data Cloud (http://www.gscloud.cn) (accessed on 16 August 2022).
Administrative divisions	Shapefile	Line	2019	Geospatial Data Cloud (http://www.gscloud.cn) (accessed on 16 August 2022).
Water systems	Shapefile	Line	2019	OpenStreetMap (https://www.openstreetmap.org) (accessed on 9 August 2022).
Land-use	Raster	30 m	2019	Geospatial Data Cloud (http://www.gscloud.cn) (accessed on 17 September 2022).
Heritage points	Text	Point	2022	AMAP (https://www.amap.com/) (accessed on 23 September 2022).

3. Methodology

The assessment of WCH suitability consists of three steps: (i) grading the WCH through AHP to obtain the heritage ontology suitability; (ii) exploring the distribution types and gathering areas of the WCH through GIS to determine the spatial distribution suitability; (iii) comprehensively assessing the environmental resistance through the MCRM and superimposing the heritage points to get the environmental suitability zoning. In addition, the correlation of WCH's attributes is conducted by SPSS to investigate the conservation strategy. The specific research framework is shown in Figure 2.

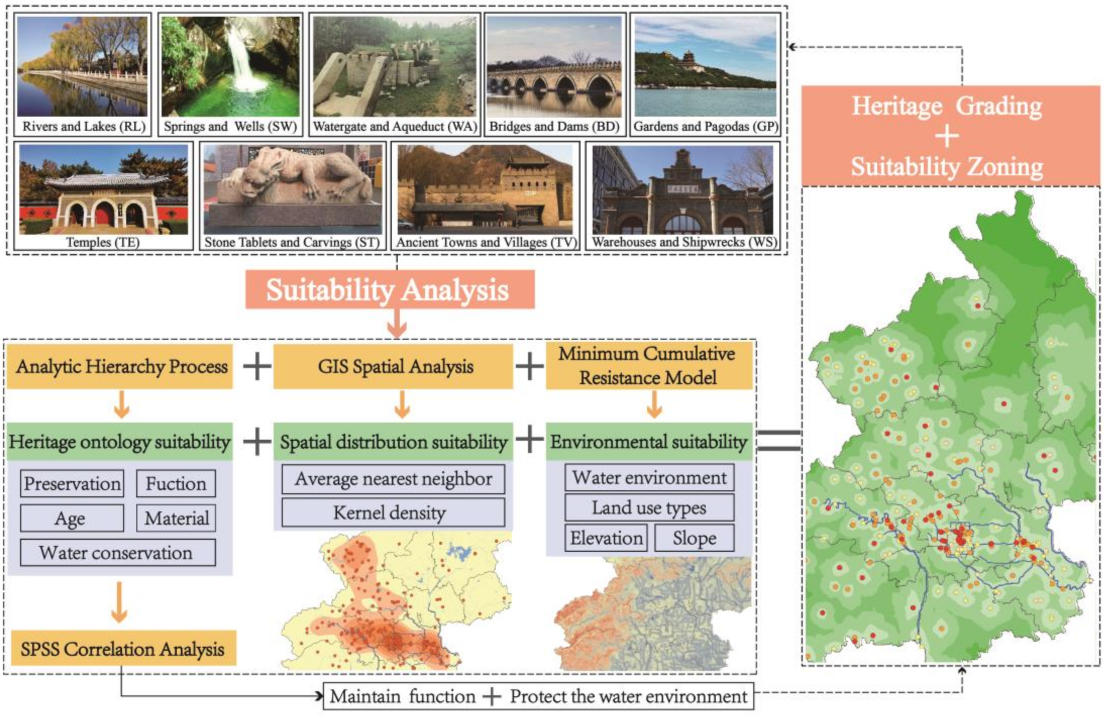

Figure 2. The water culture heritage suitability assessment framework.

3.1. Analytic Hierarchy Process and Correlation Analysis

Value assessment plays a key role in all heritage-related measures [22], which determines the development and suitability of heritage ontologies. The classifications of values encompass a wide range, including historical, economic, artistic, aesthetic, scientific, social, and an array of other types [23]. Existing evaluation indicator systems and assessment criteria were diverse and generally constructed according to the characteristics of the heritage [24,25]. Meanwhile, the scale and preservation status of Beijing's WCH vary greatly, making the assessment process very complicated [26,27]. Barbara Sowińska-wierkosz's [28] review found that the studies were mainly concerned with metrics including visual, economic relevance, social support, spatial quality, and ecological quality. Moreover, these factors were proposed based on the principles of reliability, measurability, stability, and applicability. Therefore, we identified five objective attributes for assessment based on the previous studies and the actual situation. The evaluation results were analysed by AHP, a multi-criteria decision-making method, to obtain approximate and quantitative values in five dimensions [29].

Each attribute was divided into five levels based on suitability, with each level corresponding to a score of 5 to 1 (Table 2). The purpose was to categorize WCH generically without pursuing particularly accurate evaluation outcomes: (i) The current preservation condition was the most important evaluation factor. According to the principle of integrity, the better preserved a heritage is, the more visually appealing it is. (ii) The second significant evaluation factor was the function. The construction of WCH was virtually always dependent on water demand, and the endurance of its functions was a visual indicator of economic value [30]. (iii) Age was an important influencing factor when determining historical value. The public generally tends to be more in favour of protecting age-old heritage. (iv) The robustness and preservation resistance of building materials determine the quality of the space. The robustness and preservation resistance of building materials have a significant impact on space quality. Five main building materials (concrete, brick, stone, wood, and rammed earth) were chosen for scoring. Only the 2–3 materials with the largest proportions were selected for heritage with complicated composition, and the final material score was obtained by averaging. (v) As water forms an integral part of WCH and the reduction of water area reflects the change in local ecology, the conservation of water area was also taken into account.

Table 2. Evaluation criteria for heritage ontology suitability.

Score	Preservation	Function	Age	Material	Water Conservation
5	Well-preserved	Continued today	Liao, Jin, and the previous dynasties	Concrete	Basically maintaining the status quo
4	Preserved	For other purposes	Yuan dynasty	Brick	Only 75% of the original
3	Partially remained	Landscape only	Ming dynasty	Stone	Only 50% of the original
2	Few remained	Relic exhibition only	Qing dynasty	Wood	Only 25% of the original
1	Basically non-existent	Completely lost	Modern times	Rammed earth	Complete drying up or disappearance
Weight	0.3534	0.2952	0.1323	0.1004	0.1187

This assessment system inventively integrated the characteristics of WCH and was deemed applicable to all heritage sites. Additionally, we selected relatively objective evaluation factors to reduce the error from the assessment subject. However, it was limited by the number of evaluation factors and did not provide a comprehensive and accurate representation of each heritage value.

The weights of different factors were obtained using the group decision approach. Five experts from architecture, heritage conservation, civil engineering, environmental science, and hydrology were invited to compare the importance of these five factors. The scores were approximately equal for each expert. The final weight was acquired by averaging the five experts' scores. The ontology suitability of each heritage can be calculated by Equation (1)

$$V_i = w_1 * P_i + w_2 * F_i + w_3 * A_i + w_4 * M_i + w_5 * C_i \ (I = 1, 2) \quad (1)$$

where V_i represents the final score of each heritage; w represents the weight of each factor; P_i represents the score of preservation; F_i represents the score of function; A_i represents the score of age; M_i represents the score of material; and C_i represents the score of water conservation.

In general, the preservation of cultural heritage is negatively related to age and positively related to material durability [31], but other factors may also exert impacts. To investigate the relationships between heritage attributes and pinpoint elements influencing heritage preservation, SPSS bivariate analysis was employed. The correlations measured by the coefficient r can be used to build protection strategies, which were calculated by Equation (2):

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{2}$$

where n represents the number of heritages; x and y represent attribute scores; and the correlation coefficient r lies from −1 to 1. Additionally, where $|r|$ is closer to 1, the higher the correlation; $|r|$ the closer to 0, the lower the correlation; the positive and negative signs indicate the directions of the correlation.

3.2. GIS Spatial Analysis

The suitability of the area increased with the density of its heritage. In spatial analysis, only point elements were selected because there were not many line elements and the distributions were relatively intuitive. The distribution type was typically determined using the average nearest neighbour index (R) [32], which was derived from Equations (3) and (4):

$$R = \frac{\overline{r_i}}{r_E} \tag{3}$$

$$r_E = \frac{1}{2\sqrt{m/A}} = \frac{1}{2\sqrt{B}} \tag{4}$$

where r_i represents the average distance between each heritage point and its nearest heritage; r_E represents the theoretical nearest distance when the point-like elements are randomly distributed; m represents the number of heritage points; A represents the study area; and B represents the number of point elements per unit area. When R = 1, the point elements tend to be randomly distributed; when R > 1, the point elements tend to be uniformly distributed; when R < 1, the point elements tend to be clustered distributed.

With the use of kernel density analysis tools, the aggregation area of heritage was visualized by calculating the density in its neighbourhood [33], which was calculated as Equation (5):

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \tag{5}$$

where k( ) denotes the kernel density function; n is the number of heritage points in the threshold range; h is the bandwidth; and $(x - x_i)$ represents the distance from the valuation point x to the event x_i.

3.3. Minimum Cumulative Resistance Model

Cultural heritages are strongly linked to the environment [34,35], as their construction and the formation of features are the results of a combination of natural geographical environments and human environments such as altitude, topography, river hydrology, ideological evolution, social and economic development [36,37]. Environmental conditions can significantly affect the state of conservation [38,39]. For instance, heritages in mountainous regions frequently face greater threats [40] due to high altitudes and steep slopes, making restoration more challenging. Thus, environmental resistance is a crucial aspect that must be considered for heritage development, and the MCRM may efficiently quantify it [41,42]. The cost from the "source" to the surrounding area was referred to as the minimum cumulative resistance (MCR) [43] and was calculated by adding the resistance costs of different surfaces. Using the MCRM to identify core patches and potential corridors has become the mainstream paradigm for landscape pattern optimization [44], and the calculation is given by Equation (6):

$$\mathrm{MCR} = \int \sum_{j=n}^{i=m} \left(\mathrm{D_{ij}} \times \mathrm{R_i}\right) \quad (6)$$

where, MCR is the cumulative resistance cost; D_{ij} is the spatial distance from environment i to heritage source j; R_i is the cost of resistance generated by the environment i to heritage.

We selected three impact factors like land use types, elevation, and slope, based on the comprehensive ecological characteristics of Beijing and the recommendations of the references [45,46]. As WCH is closely associated with water systems, modelling must take the water environment into account. To complete the construction of various resistance zones, the study area was divided into seven land use types, five elevation zones, and five slope sections. Additionally, a three-stage multiple-ring water buffer was established.

To construct the evaluation model accurately, we separated the resistance cost into 10 levels, with a minimum cost of 0 and an increase in the cost of 30 for each level. Experts from five pertinent study domains were invited to identify the resistance zones according to their heritage conservation project experience and theoretical knowledge. Each resistance level was determined by its average value. We rounded off and chose integers as the final resistance cost to intuitively reflect the relative magnitude of resistance in various situations (Table 3). These values are collectively useful in the evaluation system and cannot be utilized to describe the resistance of a particular region. Sharp and steep slopes present the highest obstacles to conservation activities [47] and therefore have the highest value. The same process being used to determine the heritage attribute weights was adopted to set the resistance weights. By contrasting the evaluation method with the study of Jinlong et al. [45], the overall consistency was discovered. The cost of four resistance factors was added up using the weighted sum tool to produce a comprehensive resistance surface, which visually demonstrates the suitability of the heritage environment.

Table 3. The resistance cost and weights of each resistance zones.

Factor	Resistance Zone	Resistance Cost	Weight
Water environment	Within 200 m	10	0.243
	200~500 m	30	
	500~1000 m	70	
	Over 1000m	150	
Land use types	Water	0	0.345
	Wetlands	20	
	Grassland	40	
	Shrub	50	
	Forest	60	
	Cropland	90	
	Built-up land	120	
Elevation (m)	−39~200 m	10	0.211
	201~500 m	30	
	501~800 m	60	
	801~1200 m	100	
	>1200 m	150	
Slope (%)	0~3	5	0.201
	3~8	10	
	8~15	30	
	15~25	100	
	>25	300	

The heritage source and the cost resistance surface were imported into the MCRM to obtain the environmental suitability zoning. As there is currently no established zoning standard, we divided suitability zoning into five categories using Jenks, which is the most widely used approach [45]. The quantity and proportion of heritage points in each resistance zone were determined using the intersect and extract values to points tools in ArcGIS, which reflect the overall environmental distribution of the heritage.

4. Results

4.1. Valuation of Heritage and Correlation of Attributes

The scores for each attribute of the nine WCH categories, which could reflect comprehensive conservation value, were obtained through field research and data analysis (Figure 3). The results demonstrated that the final score ranged from 2.58 to 3.85. In terms of preservation, the well-maintained heritages made up 39.76% ($p \geq 4$), whereas the inadequately preserved and non-existent heritages made up 34.04% ($p \leq 2$). The most well-preserved was RL, followed by TE, while BD was the least well-preserved. As to the functionality, about 65.96% ($F \geq 3$) of the heritages were still operational. The function of GP was best maintained, and WS lost its storage function due to the termination of shipment. The commonly used building materials were brick, wood, and stone. The structures in GP and WA were more aesthetically pleasing because their building materials were more preservation resistant. The heritages were mainly dated to the Ming and Qing dynasties, accounting for 34.04% ($A = 3$) and 31.02% ($A = 2$), respectively. The SW and BD generally experienced a longer history of construction. About 43.37% ($C \geq 4$) of the water areas were well preserved, and 41.57% were poorly preserved ($C \leq 2$). It was caused by a variety of factors, such as river diversions, declining groundwater levels, climate change, or urbanization. The water bodies around WA and RL were better preserved and had been performing irrigation, drainage, and ecological support functions in the city. Overall, the results for the nine categories varied significantly, with GP scoring the highest, followed by RL and WA.

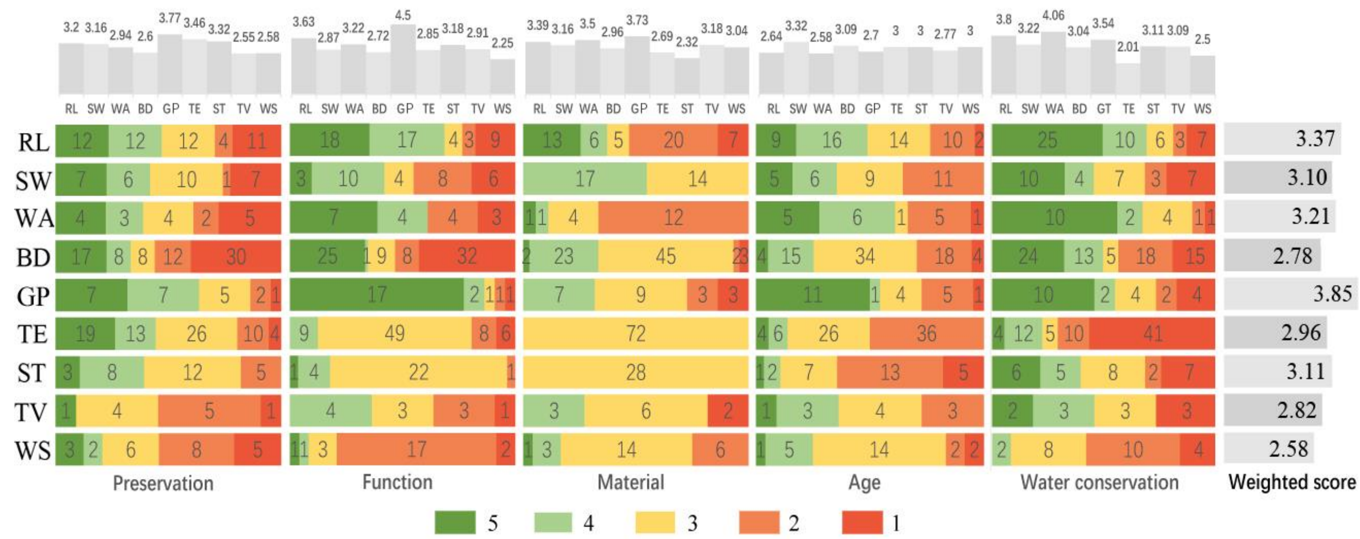

Figure 3. The distribution and average scores of each attribute.

A more intuitive picture of the weighted heritage scores was obtained by superimposing weights for each factor and summing them together. The final scores ranged from 1.1 to 4.9, with an average of 3.05 and a standard deviation of 0.96. The standard deviation represented a significant difference in the scores. Four classes could be approximately distinguished on this basis (Table 4), with heritage ontology's suitability decreasing as the scores decrease. The share of important and common heritage was about 62%, and the percentage of core and minor heritage was 38%. In addition to having a linear distribution, the river heritages with the characteristic of linear distribution were well preserved, serve crucial ecological functions, and have a long history, making them fall under the category of core heritages. All the heritages listed on the *Beijing Hydraulic Heritage List* and *Heritage Protection List* above the city level belong to the core heritage category, indicating the validity of the assessment result.

Table 4. Heritage classification.

Heritage Class	Final Score	Quantity
Core heritage	4~5	61
Important heritage	3~4	102
Common heritage	2~3	104
Minor heritage	1~2	65

The correlation between heritage attributes reflected the extent to which two factors influence each other (Table 5) and revealed the internal logic of heritage development. The results showed a significant positive correlation between the preservation and function of the WCH and a moderately positive correlation with the conservation of the water area upon which the heritage was based. At the same time, there was a moderately positive correlation between the heritage function and the conservation of the water area. The remaining relationships were very weak or non-existent.

Table 5. Correlation of attributes of WCH in Beijing.

Factors	Preservation	Function	Age	Material	Water Conservation
Preservation	1				
Function	0.702 **	1			
Age	−0.069	−0.014	1		
Material	0.126 *	0.245 **	−0.149 **	1	
Water conservation	0.517 **	0.503 **	0.179	−0.067	1

The symbol of ** indicates significant correlation ($p < 0.01$) at the 0.01 level. The symbol of * indicates significant correlation ($p < 0.05$) at the 0.05 level.

4.2. Heritage Gathering Area

Point element distributions can usually be classified as random, uniform, or clustered [32,48]. The average nearest neighbour index of Beijing's WCH produced R = 0.927, i.e., R < 1, meaning that its spatial distribution was considered condensed.

We discovered through kernel density analysis that WCH structures are mainly distributed in central and south-central Beijing, sharing significant characteristics of regional clustering, proximity to densely populated areas, and distribution along rivers. There are four significant aggregation areas (Figure 4). (I) The first area is the old town built in the Ming and Qing dynasties and its surroundings, which had the highest heritage density and a circular distribution. (II) The second heritage zone is along the Grand Canal in Tongzhou District, which is linearly distributed. (III) The third is the border area of the Haidian and Mentougou Districts, which is distributed around the royal garden of the Qing Dynasty and the Yongding River. (IV) The fourth area is the southwestern part of Yanqing District, which is mainly composed of temples (TE) in a scattered distribution.

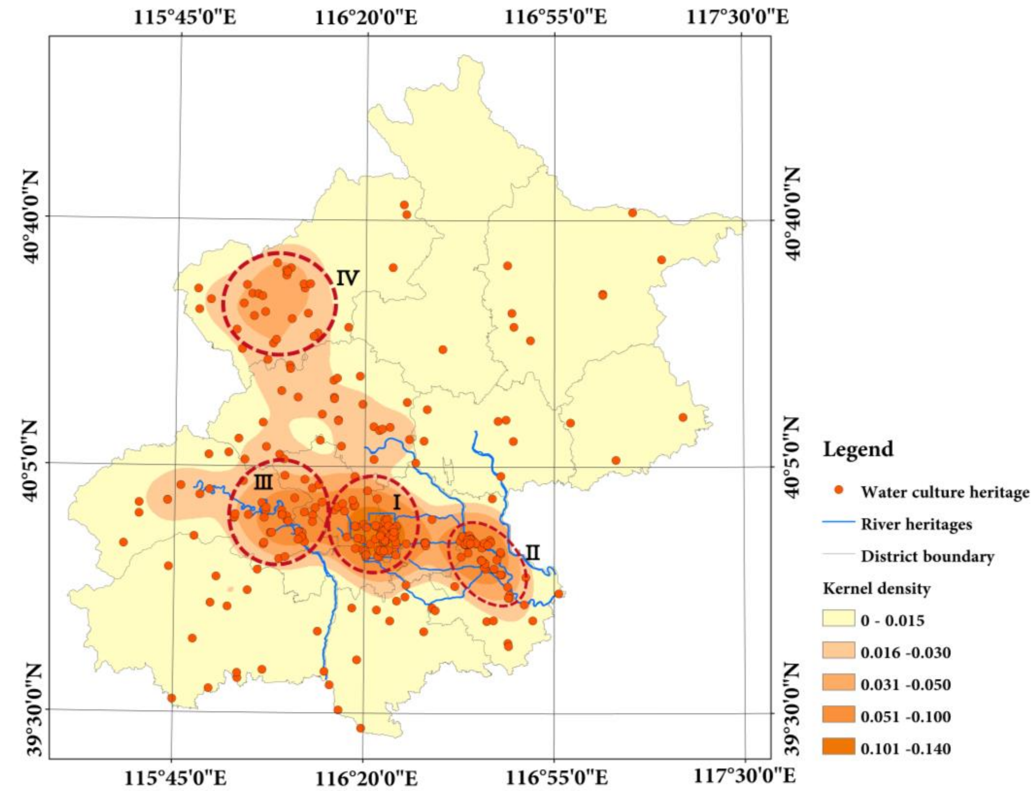

Figure 4. Kernel density map of WCH in Beijing.

4.3. Minimum Cumulative Resistance

The heritage's overall environment reflects the main sources of resistance, which is an external factor that should be considered for targeted conservation. The findings revealed the following distinctive characteristics of Beijing's WCH distribution and its surrounding environment (Figure 5 and Table 6). (i) There is a visible aggregation along the river, where more than 80% of the heritages are close to and assembled within 1000 m of the water system. (ii) Clustering in the metropolitan areas and the villages (built-up land and cropland) of the region, where the natural water system is most frequently modified. (iii) Gathered in low-lying plains and valleys (−39~200 m above sea level) that are suited for agricultural and urban growth, with the number of heritages declining as altitude increases. (iv) The number of heritages decreases as the slope rises. Around 80% of the heritage sites are on gentle or moderate slopes (0–8 degrees), with only 4.7% located on sharp or steep slopes (>25 degrees). Since the beginning of its construction, environmental characteristics of heritage had been determined. The WCH structures were mostly built out of the need for flood control, navigation, and irrigation [49]. Mountainous areas had harder topography, steeper slopes, and faster water flow, which made it harder to use the water and reduced the number of heritages. On the other hand, the plains and valley regions had moderate slopes and fertile soils, which helped them accumulate a significant amount of heritage. Generally, the abundance of WCH structures in each environmental category reflected the influence on human-water interaction.

The ultimate resistance cost obtained by MCRM ranged between 5.545 and 157.650 (Figure 6). It was divided into five levels using the equal spacing method in the reclassify tool. The overall development environment for Beijing's WCH is relatively favourable, as 80.84% of the resistance cost was below 96.808 (Table 7). Generally, the western mountains have lower suitability than the central plains due to their slope and elevation constraints. In general, protection should be prioritized for areas with lower resistance.

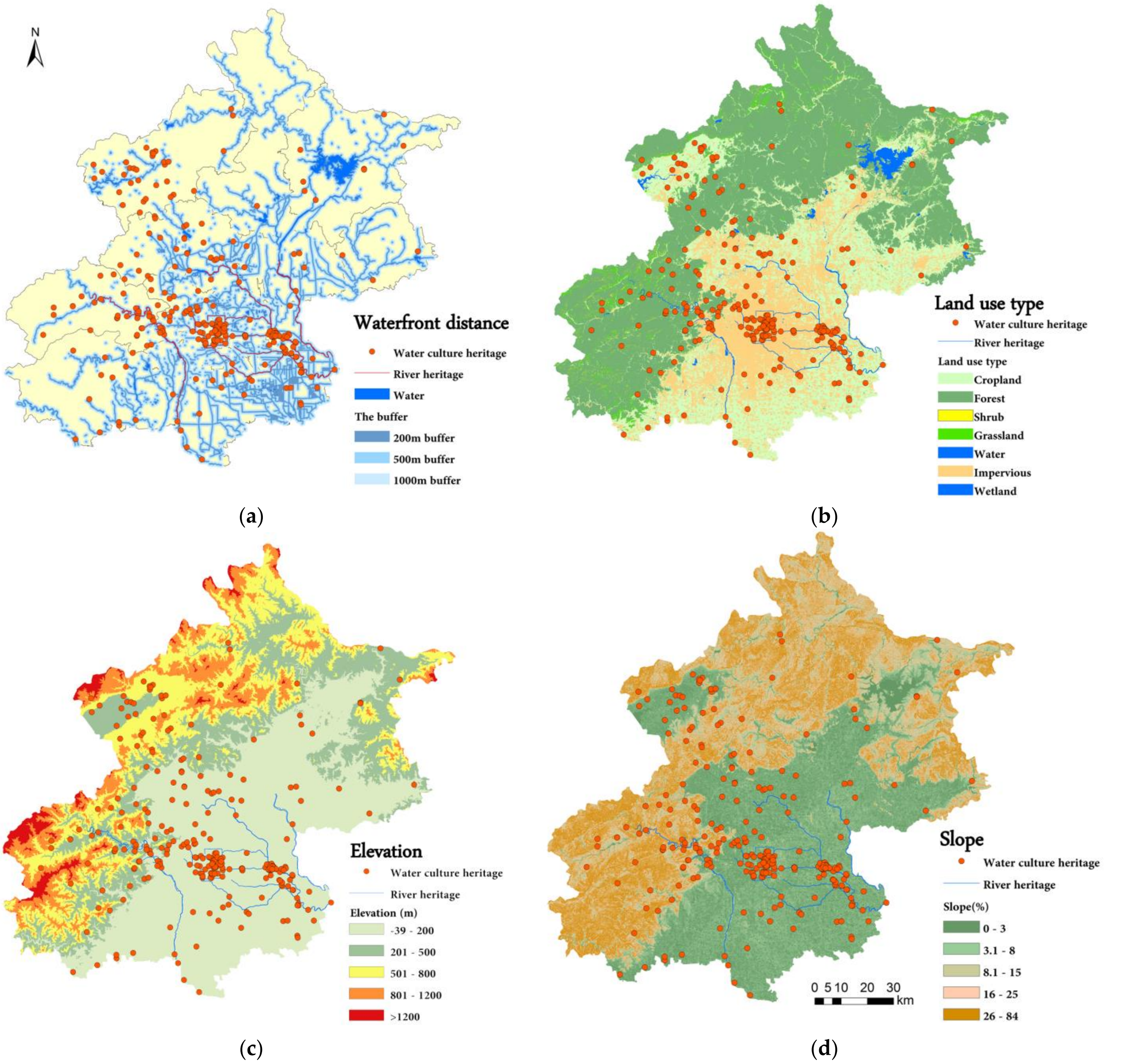

Figure 5. Environment distribution of WCH in Beijing: (**a**) waterfront distance; (**b**) land use type; (**c**) elevation; (**d**) slope.

Table 6. The proportion of the environment distribution.

Waterfront Distance (m)		Land Use Type		Elevation (m)		Slope (%)	
Within 200 m	39.93%	Water	8.05%	−39~200	74.16%	0~3	45.30%
200~500 m	22.15%	Grassland	1.34%	201~500	16.11%	3~8	34.23%
500~1000 m	19.46%	Cropland	14.77%	501~800	8.72%	8~15	10.40%
Over 1000 m	18.46%	Forest	12.08%	801~1200	1.01%	15~25	5.37%
		Built-up land	63.76%	>1200	-	>25	4.70%

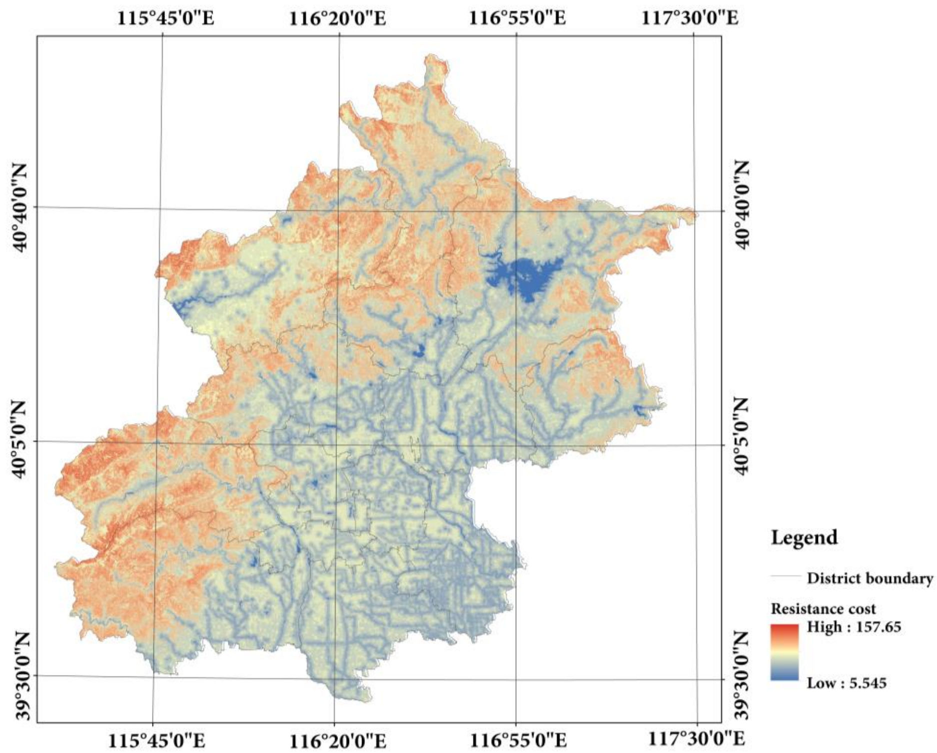

Figure 6. The resistance cost map.

Table 7. The area ratio of resistance cost and suitability zoning.

Resistance Cost	Area Ratio	Suitability Zoning	Area Ratio
5.545~35.966	2.38%	High suitability	21.70%
35.967~66.387	53.04%	Middle-high suitability	37.85%
66.388~96.808	25.42%	Middle suitability	21.72%
96.809~127.229	17.97%	Low suitability	15.11%
127.230~154.650	1.19%	Unsuitable	3.62%

4.4. Suitability Zoning

To generate the suitability zone in Beijing, multiple resistance factors were considered, and a comprehensive index weighting method was applied. The city region was split into high suitability, middle-high suitability, middle suitability, low suitability, and unsuitable areas (Figure 7) by superimposing the heritage points and resistance surface sources. Overall, the middle–high suitability area was discovered to be the largest, followed by the high and middle suitability areas (Table 7). The southern area of Beijing is much more suitable than the northern area. Based on the size and shape of the high suitability areas surrounding each heritage site, we were able to determine the relative magnitude and direction of the comprehensive resistance. The clustering of heritages leads to the overlap of the high suitability areas and increases suitability. Moreover, there is an obvious spatial association between the high suitability areas and linear river heritages, proving that the construction of heritage corridors is appropriate for WCH integrated protection. Different levels of WCH are distributed uniformly in space, which made the delineation of core protection areas relatively difficult. As of the present, the WHCs along the North Canal, Shichahai, and royal garden are prospering, and the fact that each of these zones falls within the high suitability area proves the validity of the results. In summary, heritage managers should focus on the preservation of the old city, along with important rivers and core heritage sites, in the future.

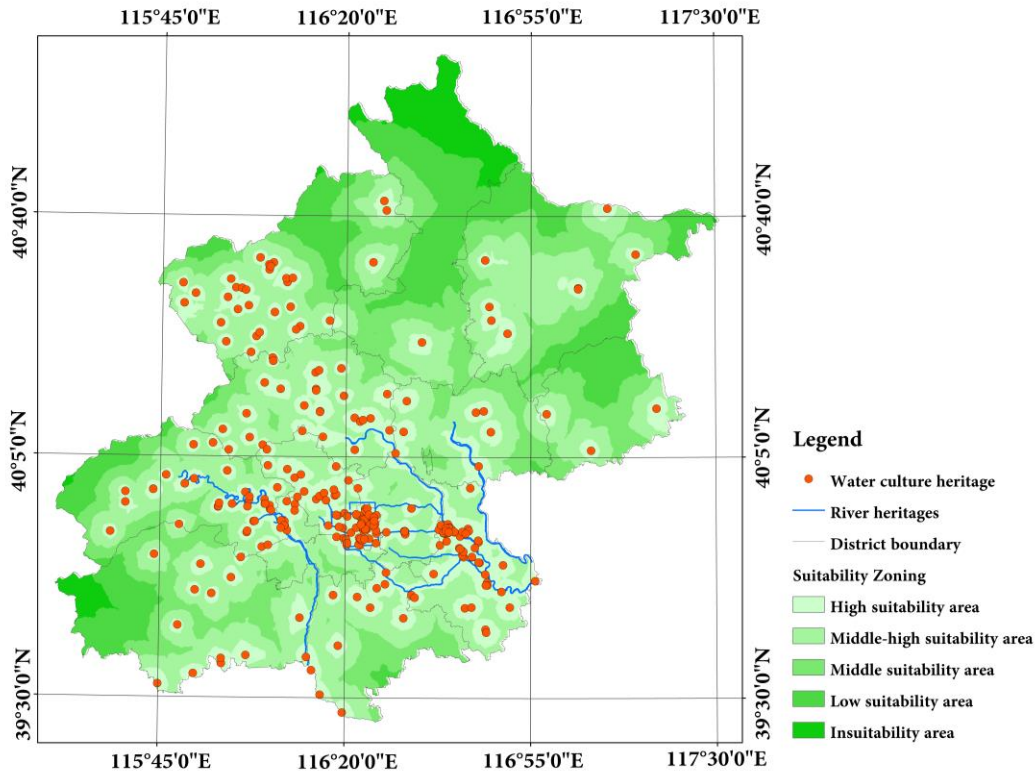

Figure 7. Heritage grading and Suitability zoning.

5. Discussion

5.1. Cultural Characteristics and Policy Impact

It is necessary to sort out the cultural characteristics of heritage before developing a conservation plan. As the physical vehicle for the operation rules of the regional hydrological system, WCH structures contain a variety of water management intelligence from ancient times. The formation of cultural identity correlates closely with the history of the city and presents three distinct features: shipping, agriculture, and royalty [12], which correspond to its important role in the dissemination of civilization. Specifically, several heritages have a significant relationship with shipping along the Grand Canal and Tonghui River, including BD, WS, TV, and various other types. The origins of agriculture culture can be traced back to water-related beliefs and technology, and its main heritage types are temples, stone tablets, ancient wells, and irrigation channels scattered throughout the city's suburbs. On the other hand, the heritage of the gardens, springs, and lakes, mostly located in and around the old city, makes up the royalty culture. Therefore, rapid urbanization accelerated the decline of agriculture and shipping cultures. While the royalty-related heritages, which have survived due to their unique status and superior location, are well preserved and retain high comprehensive value.

The policy has significant impacts on the prospects of heritage [50]. In recent years, Chinese cities have shifted toward high-quality development, and the construction of waterfront spaces has drawn more attention. Especially after the promulgation of "The 14th Five-Year Plan" for the construction of water culture, massive measures such as river and lake governance and ecological water replenishment [51] have effectively improved the water quality and significantly raised the groundwater level [52]. Consequently, the prospect of preserving and utilizing WCH is generally promising.

5.2. Suitability for Heritage Development

Beijing's WCH structures are numerous and diverse, but the grading of heritage has not been completed, making it difficult to advance conservation measures [11]. The value of the heritage ontology can be roughly measured by the AHP rating of its attributes to determine the core heritage and priority protection level. Rational allocation with limited resources is essential [53]. In terms of spatial distribution, WCH structures are scattered in extensive regions and difficult to integrate. Through kernel density analysis, it is possible to identify heritage agglomerations and thus delineate limited protection areas. The establishment of a conservation framework relies on the identification of spatial elements. Additionally, a minimum resistance model was constructed for quantitative analysis to measure the possible resistance caused by multiple external environments. Identifying environmental factors of high resistance helps to anticipate possible risks and to develop targeted protection measures. The results of the heritage classification and cumulative resistance surface sources were superimposed to obtain the final suitability zoning. We constructed a comprehensive evaluation framework for WCH from three aspects of "nature–society–space", which are considered the main problems in heritage conservation, and thus the results are informative for follow-up work [42,54]. In conclusion, it seems that Beijing's WCH structures have good development suitability owing to their rich cultural connotations, superior location, and suitable environment. However, some non-core heritages located in remote mountainous areas face serious risks and threats [40]. In the period of rapid urbanization, it is necessary to construct a corresponding conservation plan to perpetuate the ancient wisdom of water management.

5.3. Protection Framework and Strategy

Beijing's WCH presents a spatial distribution pattern of "one centre, two wings, one area, and multi-node" on a macro level. The old city is the core with the highest heritage density. The east and west wings are the areas along the Yongding River and the Grand Canal, and the southwest part of Yanqing District is a separate area. A multi-node is formed by a number of the core heritages being scattered outside the aggregation area. Wang Changsong [6] once pointed out similar aggregation zones. Because of their distinct and varied styles, specialized conservation methods are necessary [12].

The distribution of WCH structures along the rivers is apparent at the mesoscopic level, making it possible to create heritage corridors for comprehensive conservation and utilization. When exploring the construction of the Grand Canal heritage corridor, both Yu Kongjian [55] and Wang Jianguo [56] suggested that holistic conservation relying on the river can help mitigate environmental resistance. Currently, the building of the Grand Canal and Yongding River cultural belt have been mentioned in the *Master Plan of Beijing (2016–2035)* [57], but other heritages still lack clear protection policies, which calls for integrated protection for other important river heritages.

At the micro level, the overall value of each heritage varies significantly. According to the scoring results, the categories of GP, RL, WA, and the 65 core heritage items ($V_i \geq 4$) should be prioritized for protection. Heritages distributed in villages, mostly with high elevations and steep slopes [36], are difficult to integrate and their conservation should be promoted in conjunction with the traditional culture of the villages.

The analysis of heritage attributes reveals that function and water conservation has a stronger influence on preservation than age and materials. The deeper root cause may be that humans have been more likely and more frequently to repair or even rebuild the heritages whose functions are still needed. Heritage revitalization for the purpose of performing ecological and social functions is comparatively common [58]. The function of WCH is strongly tied to the water environment, as it can be weakened or eliminated due to the drying up of the water body [4], thus affecting the degree of their preservation. Therefore, the historical functions of WCH should be maintained or replaced with new ones to meet contemporary practical demands. Water systems and their ecology should also be protected, as they are essential for heritages to perform their functions.

5.4. Uncertainties and the Explanations of the Results

First, these research objects were included in the results of the first WCH investigation because the results were comprehensive and complete. However, some heritage sites have not been included because the relevant research system is not yet fully mature, which may affect some of the perspectives. Second, AHP analysis is inevitably influenced by subjective cognitive perception [59]. The scoring of heritage values adopted a rough classification and did not reflect accurate results. Although the final scores were verified and proved to be consistent with reality to demonstrate their credibility, it is necessary to examine more comprehensive value assessment methods for a more detailed and precise grading of WCH in the future.

Despite the considerable uncertainties, the study represents a valuable step toward understanding and safeguarding the WCH. The framework realized a measurable and visual approach for heritage assessment and environmental impacts, providing available information for protection and management. At the municipal level, the status quo of Beijing's WCH and its overall characteristics are discussed in this paper. Although the results are inadequate for explaining the comprehensive condition of a specific heritage, they provide a certain reference for the subsequent step of scientific conservation planning.

6. Conclusions

The focus of this study was the suitability analysis and protection approach of water cultural heritages in Beijing because these heritages have demonstrated the wisdom of water management and the interactions between humans and water. In addition to proposing a set of suitability analysis methods contributing to the development of a conservation framework, we discussed the overall characteristics of the WCH in Beijing. First, the suitability of the heritage ontology was obtained by AHP, and a preliminary ranking was made. According to correlation analysis, maintaining functions and protecting the water environment are both indispensable for WCH preservation. Secondly, ArcGIS spatial analysis was utilized to identify the spatial distribution suitability, revealing that the heritages were close to densely populated areas, distributed along rivers, and had four significant concentrations. Finally, the quantitative analysis of environmental suitability based on MCRM was completed to determine the suitability zoning. On this basis, the cultural characteristics of shipping, agriculture, and royalty were sorted out, and the impact of policies was discussed. We formulated a development strategy for Beijing's WCH and built a "one centre, two wings, one area, and multi-node" conservation structure, which proposes the directions to be taken in the future. This approach makes it easier to clarify development priorities, identify critical regions and environmental constraints for many WCH structures of diverse types and with significant differences. It may serve as a model for other cities to help decision-makers devise effective conservation plans.

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