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Quantitative evaluation of plants on top surface of the Great Wall in Dazhuangke using the analytical hierarchy process

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Abstract

The Great Wall of China was a military facility that has been continuously built and used for over thousands of years, and is a world-renowned cultural heritage site today. The plants growing on top surface of the Great Wall caused the damage of the Great Wall, but the process of removing these plants may further damage the body of the Great Wall. In this paper, based on the Analytic Hierarchy Process and the expert Delphi method, we selected 13 specific indices from three Constraint Layer factors, and then estimated and identified 45 species/categories of plants on top surface of the Dazhuangke section of the Great Wall. The results showthe constitution and the evaluation gradeof the evaluation system. The factor of Disruptive Effects plays the main guidance role in the evaluation system of the Constraint Layer; The indices of Impact on the Near Side Wall is the core element of the evaluation model with the highest weight of the Standard Layer. And the "Preservation", "Partial Preservation"and "Removal" recommendations were given based on three evaluation grade (from Grade I to Grade III). This research provides scientific basis for the protective repair of the Great Wallheritage as well as "Garden on the Great Wall".

Keywords Heritage conservation, Deterioration of the Great Wall, Plant landscape, Landscape management, Sustainable development

Introduction

The Great Wall of China is an ancient military defences project with the longest cumulative construction time in the world [1, 2]. Since the Great Wall was announced as the first national cultural relic to be protected by China's State Council in March 1961 and listed as a World Heritage Site (No. 438) in December 1987, its protection and repair have received increasing attention from the government and society [3]. In particular, issues related to how to repair the Great Wall and dispose of the plants on the top surface of the Great Wall (hereinafter referred to as Wall-Top Plants) have attracted much attention [4, 5].

Since the beginning of twentieth century, researchers in the field of the protection and restoration of historical buildings have examined the relationship between historical building sites and the plants in the area, as well as the disposal methods of the plants. Cesare Brandi (1906–1988), an Italian scholar, regarded historical buildings and plants as one entity, and he preserved the plants in the site area for practical and aesthetic purposes and proposed the concept of critical restoration [6–8]. In the 1970s, some researchers believed that there was a relationship, either direct or indirect, between the damages of building sites

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and the plants and that preserving plants was equivalent to accelerating the destruction of the sites; they believed that plants should be removed to prevent damage, and they applied concrete to protect historical building sites after removing all the plants [9]. In the 1990s, based on several studies and practices, some researchers thought that this "hard cover" method may accelerate the destruction of historical building sites [9]. As early as the 1930s, in view of the principle of "conserve as found" and the preservation of Hadrian's Wall by John Clayton in the 1830s [10], British scholars proposed and implemented the "soft cover" method in the1980s. The method was successfully applied in the military fortress of St. Mary Island in Scotland [11]. At the same time, evidence from geomorphology and ecology research confirmed the efficacy of this method in 1993 [11]. The soft cover (or soft capping) method has since undergone many improvements and is widely used in Nordic countries [9–12].

The heritage of the Great Wall takes "the form of ancient buildings and ancient ruins, with ancient ruins as the main surviving form" [1–3, 13], which means that the Great Wall should be repaired in the way that least affects this heritage (the principle of "minimal intervention") [3]. According to various studies, the Wall-Top Plants have a dual influence of destruction and protection on the body of the Great Wall during their growth period [4, 14, 15]. The removal of the Wall-Top Plants is necessary from the perspective of the damage already caused and the potential threat. At the same time, however, some plants have not yet threatened the structural safety of the Great Wall, and the removal of these plants may in fact endanger it. Moreover, from the perspective of the overall value of the Great Wall, the Wall-Top Plants are an important part of the Great Wall's historical and cultural landscape and have irreplaceable preservation value [16–18]. Thus, in view of the complex relationship between the Great Wall and the Wall-Top Plants, a systematic selection of plants based on respect for the complexity and uniqueness of the site's environment is the key to analyzing the Wall-Top Plants comprehensively.

The analytic hierarchy process (AHP) is a multi-level quantitative research methodology that is applied to research objects with complex features [19–22]. This study seeks to answer two research questions: (a) What kinds and quantities of plants are distributed on the top surface of the Great Wall? (b) Which types of plants affect the structural safety of the Great Wall and should be removed and which are valuable for preservation? We put forward suggestions regarding the retaining or removing of the plants according to the plant evaluation, with a view to providing a scientific basis for the implementation of the Great Wall's conservation and renovation.

Research case

As shown in Fig. 1, the Great Wall of China is 21,196.18 km long, with a wide geographical span and a diverse natural climate in different regions [1, 2]. The Beijing area is one of the concentrated distribution areas of the Great Wall. The length of the Great Wall in this area is 527.65 km [3]. The area has three windy seasons in spring, autumn, and winter, with heat and rain in July, August, and September. Various native plant varieties grow in this area, with a forest cover of about 44.8%. The Beijing Great Wall has a semi-ring shape and is mostly a masonry wall built during the Ming Dynasty (AD1368–1644), as shown in Fig. 1 [4, 5]. The Dazhuangke section of the Beijing Great Wall (hereinafter referred to as the Dazhuangke Great Wall) is located along the southeast boundary of Yanqing District and was built in the early Ming Dynasty. It starts 1.4 km east of Longquanyu Village, Dazhuangke Township, and ends at a cliff 0.7 km to the southeast of Songshugou Village, with a total length of about 7.5 km. The sample section for plant investigation in this survey was mainly the top surface area of the Dazhuangke Great Wall between No.2 and No.5 Enemy Station and its adjacent section. The survey route is shown in Fig. 1, with a total length of about 800 m and a total area of about 2800 m^2.

From 2020 to 2022, the Wall-Top Plants of the Dazhuangke Great Wall were investigated and recorded, and the fieldwork covers three growing seasons. Thirty-six species of plants (25 native plants of the Beijing region, four national or local protected plants, and two exotic plants) were found in the study area, belonging to 20 families and 32 genera. In terms of the plants' biological characteristics, there are 21 species of deep-rooted plants, 13 species of shallow-rooted or fibrous root system plants, and two species of abnormal stem plants (Figs. 2, 3, 4).

Development of plant evaluation system and scoring criteria

Based on previous literature [19–22], we developed the AHP scoring criteria using the Delphi method. Twenty experts from research fields such as ecology, landscape architecture, and historical building protection and restoration were invited to assign values to the judgment matrix. Based on the goals and current status of the protective repair of the Great Wall, the experts proposed the evaluation indicators of most concern in their respective fields. After discussion, different levels of the evaluation indicators and their weights in the AHP evaluation system were determined. Finally, we constructed a complete evaluation system that allows comprehensive evaluation of the Wall-Top Plants as the Target Layer (*A*); Biological Characteristics,

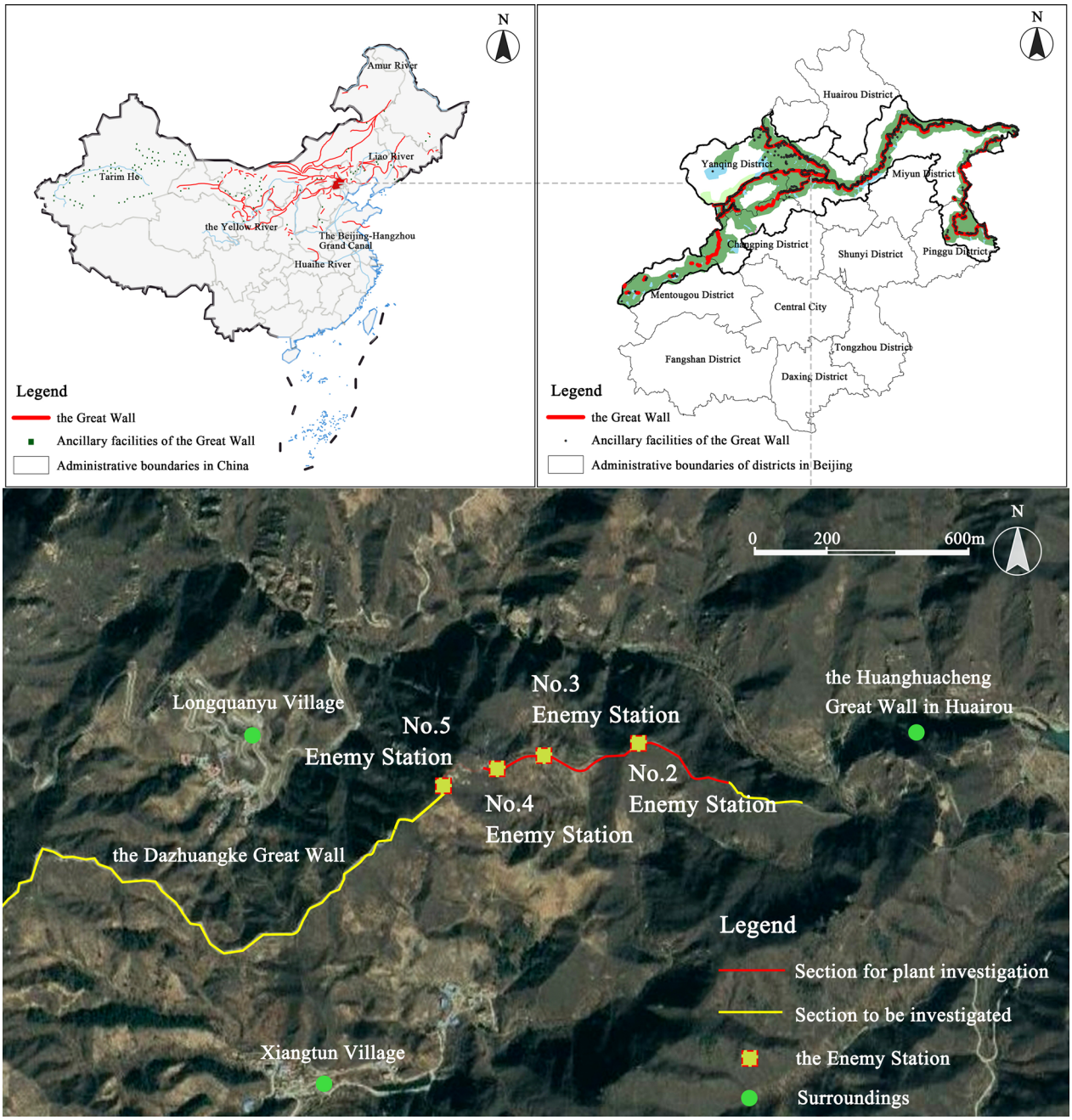

Fig. 1 Location of the Dazhuangke Great Wall

Damage Impact, and Application Value as Constraint Layer indicators (*C*); and 13 specific indicators as the Standard Layer (*P*). The Wall-Top Plants were assigned scores of 5, 3, 1 or 0, with the lower scores representing a stronger impact of the Wall-Top Plants on the Great Wall, and vice versa (Table 1).

Determination of index weights and consistency tests

Two judgment matrices, *C* and *P*, were constructed, and the index factors of each grade were compared in pairs. To improve the accuracy of the results, the assignment used a scaling method of 1–9. The evaluation results of all the experts are summarized, the consistency of the judgment matrix is tested according to the following calculation steps, and the final consistency test value (*CR*)

Fig. 2 The Dazhuangke Great Wall. **a** Before protective repairs; **b** Deterioration of the Dazhuangke Great Wall; **c** After protective repairs

Fig. 3 Comparison of the Wall-Top plant of different diameter (D). **a** D ≤ 10 cm; **b** D > 10 cm

Fig. 4 The status of the Wall-Top Plant root invasion. **a** Trees and shrubs; **b** Herbs

is compared with the value 0.100. If $CR < 0.100$, the judgment matrix is valid. Otherwise, the judgment matrix must be adjusted until the test is passed. The calculation steps are as follows [19–22]:

Calculate the square root vector of the judgment matrix, A_i [19, 20]:

$$A_i = \sqrt[n]{\prod_{i=1}^{n} E_{ij}} \left(i = 1, 2, \ldots, n; j = 1, 2, \ldots, n\right) \quad (1)$$

E_{ij}: scale value of the relative importance of the i-th factor to the j-th factor ($i = 1, 2, \ldots, n$; $j = 1, 2, \ldots, n$; n: number of evaluation indicators).

Table 1 Comprehensive evaluation index system and scoring criteria for Wall-Top Plants

The Target Layer (*A*)	The Constraint Layer (*C*)	The Standard Layer (*P*)	Index scoring					Definition of indicators
			Evaluation grading	5	3	1	0	
Comprehensive evaluation of plants on top surface of the Great Wall	C_1 Biological characteristics	P_1 Plant type	Annual and Biennial Herbs	✓				Plant Life Type (Under habitat conditions on top surface of the Great Wall)
			Perennial Herbs	✓				
			Shrubs	✓				
			Arbor	✓				
		P_2 Plant diameter /cm	Less than 1				✓	Diameter of the main stem of arbour and shrubby trees near top surface of the Great Wall
			1–2.9			✓		
			3–6.9		✓			
			Greater than 7	✓				
		P_3 Plant height /cm	Less than 9				✓	Height of Arbour/Shrubs
			10–99			✓		
			100–299		✓			
			Greater than 300	✓				
		P_4 Growing condition	Poor				✓	Plant growth potential level
			General			✓		
			Better		✓			
			Excellent	✓				
		P_5 Intrusiveness	Pole-strength				✓	The depth and horizontal amplitude of the distribution of plant root types, from which the intensity of the attack that plants may produce can be determined
			Stronger			✓		
			General		✓			
			Poor	✓				
		P_6 Regenerative capacity	Pole-strength				✓	Plant regeneration, adaptation to the environment (survival in adversity) and ability to spread seeds
			Stronger			✓		
			General		✓			
			Poor	✓				
	C_2 Disruptive effects	P_7 Impact on the near side wall	Within range (Arbor and Shrubs)				✓	The size of the plants which inside and outside the nearside wall area[a] may cause dropsy, collapse, cracks, and deformation of the side wall
			Within range (Herbs)		✓			
			Out of range (Arbour and Shrubs)	✓				
			Out of range (Herbs)	✓				
		P_8 Impact on the top surface of the walls	Serious				✓	Dislodged, displaced and broken brickwork on top of walls caused by plants
			More Serious			✓		
			Lighter		✓			
			No Impact	✓				

Table 1 (continued)

The Target Layer (*A*)	The Constraint Layer (*C*)	The Standard Layer (*P*)	Index scoring					Definition of indicators
			Evaluation grading	5	3	1	0	
		P_9 Influence of encroachment and decay	Serious				✓	Exposure and coiling of plant roots (To determine the encroachment and decay strength of the wall)
			More Serious			✓		
			Lighter		✓			
			No Impact	✓				
		P_{10} Biological nests	Large quantity				✓	Distribution of small mammals, birds, reptiles and insect nests around plants
			More			✓		
			A Little		✓			
			None	✓				
	C_3 Application value	P_{11} Historical and cultural value	No value				✓	The recorded situation of plants in historical documents and plant archaeology
			General Value			✓		
			A More Important Value		✓			
			Important Value	✓				
		P_{12} Ecological value	No value				✓	Plant ecological benefits (reduced rainfall rates, flow velocity, etc.)
			General Value			✓		
			A More Important Value		✓			
			Important Value	✓				
		P_{13} Landscape value	No value				✓	Plant landscape features (flowers, fruits, leaves, branches and trunks, etc.)
			General Value			✓		
			A More Important Value		✓			
			Important Value	✓				

[a] 1 "Near Side Wall area" refers to the range of 50 cm from inside the side wall of the Great Wall to the midline of top surface of the Great Wall

Calculate the single-layer ranking weight value of each standard layer evaluation index, G_i:

$$G_i = A_i \frac{1}{\sum_{i=1}^{n} A_i} (i = 1, 2, \ldots, n) \tag{2}$$

Calculate the maximum characteristic root, λ_{max} [22]:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{1}{nG_i} \sum_{j=1}^{n} X_{ij} G_j \tag{3}$$

Calculate the comprehensive consistency index [22]:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

Test the consistency [21]:

$$CR = \frac{CI}{RI} \tag{5}$$

Note: RI is the average random consistency index.

Comprehensive evaluation model

The judgment matrix conforming to the consistency test results was weighted and calculated to obtain the comprehensive weight value of each factor layer element relative to the target layer, and then the test was carried out to ensure that the whole system meets the consistency requirements. Finally, combined with the scores of each Wall-Top Plant, the comprehensive scores of the plants were calculated.

The formula for calculating the composite score value (I) is as follows:

$$I = \sum_{i=1}^{n} W_i F_i \quad (6)$$

W_i: Comprehensive ranking weight value of each evaluation index;

F_i: Score value of the i-th plant.

Results

Indicator system and weight of the evaluation model for the Wall-Top Plants

As shown in Table 2, the ranking results of the constraint index weight are C_2 (Disruptive Effects) > C_3 (Application Value) > C_1 (Biological Characteristics). The core element of the evaluation model is C_2 (Disruptive Effects). According to the weight value, the top five indicators of the standard layerareP_7 (Impact on the Near Side Walls) > P_8 (Impact on Top Surface of the Great Wall) > P_9 (Influence of Encroachment and Decay) > P_{10} (Biological Nests) > P_5 (Intrusiveness). The bottom five are P_3 (Plant Height) < P_2 (Plant Diameter) < P_1 (Plant Type) < P_6 (Regenerative Capacity) < P_4 (Growing Condition). According to the ranking results, the 20 experts believe that, in the screening process of the comprehensive evaluation indices, the most significant influencing factors are the damage to the top surface of the Great Wall and especially the damage to the side wall. This indicates that, in the screening evaluation, this score has a direct influence on the damage impact; that is, it has a direct role in determining whether plants should be removed or preserved.

The survival of Wall-Top Plants depends on the physical environment of the Great Wall itself. In combination with the current situation of the Dazhuangke Great Wall, some of the Wall-Top Plants are a direct threat to the safety of the Great Wall due to their root growth, and this threat urgently needs to be addressed. On the other hand, the plants are part of the history of the Great Wall and also part of its cultural landscape. They play an important role in the integrity of the cultural landscape and aesthetic value of the Great Wall, and so they should be considered in the comprehensive evaluation. As mentioned above, the weight ranking results of the comprehensive evaluation index of the Wall-Top Plants are consistent with this understanding.

AHP comprehensive evaluation and classification of the Wall-Top Plants

As shown in Table 3, the AHP comprehensive evaluation and classification involved 36 species of plants (including 10 species of arbour plants, 11 species of shrubs, and 15 species of herbs) that grow on the top surface of the Great Wall. The results were divided into three grades: Grade I (3.000–5.000), Grade II (2.000–2.999), and Grade III (0–1.999).The analysis of the three grades of the Wall-Top Plants produced the following results:

(1) Grade I includes 16 species of herbs and two species of shrubs. Among them, annual, biennial, and perennial herbs cause destructive harm because of their short growth period, small size and shallow root system. The two factors of the constraint layer,C_1 (Biological Characteristics) and C_2 (Disruptive Effects), have higher sub-score value than C_3 (Application Value). The two species of shrub *Spiraea fritschiana* and *Spiraea trilobata* had high application value and did not cause obvious damage to the side wall or the top surface of the Great Wall, because of their shallow-root or fibrous root systems. Thus, the comprehensive score for the plants in this grade was higher than for those in other grades.

(2) Grade II includes nine species of tree, including *Morus mongolica*, *Robinia pseudoacacia*, *Armeniaca vulgaris*, *Prunus salicina*, *Pyrus betulifolia Bunge*, *Morus australis*, *Ziziphus jujuba*, *Amygdalus davidiana*, and *Juglans mandshurica*; nine species of shrub, including *Deutzia parviflora*, *Macluratricuspidata*, *Vitex negundo* var. *heterophylla*, *Rhamnus parvifolia*, *Lespedeza bicolor*, *Grewia biloba*, *Ilex crenata*, *Campylotropis macrocarpa*, and *Leptopus chinensis*; and two species of herb near the side wall, *Polygonatum sibiricum* and *Bupleurum chinense*. Unlike those in Grade I, the plants in this grade are mostly trees and shrubs, and the score of the standard layer is characterized by a higher C_3 (Application Value) (ecological and landscape value). However, the position near the side wall and the limited growth conditions on the top surface of the wall lead to a lower score in C_1 (Biological Characteristics) in the constraint layer and a higher damage impact, resulting in a lower total score.

(3) Grade III mainly includes five species of tree and shrub, *Amygdalus davidiana*, *Armeniaca vulgaris*, *Deutzia parviflora*, *Vitex negundo* var. *heterophylla*, and *Lespedeza bicolor*. The plants in this grade grow in the near side wall area and have the lowest score in C_2 (Disruptive Effects) in the constraint layer, resulting in a low overall score.

Discussion

The quantitative and comprehensive analysis above leads to the following conclusions, which can inform the research-based restoration of the Great Wall:

1. The annual, biennial and perennial herbs and low shrubs in Grade I of the comprehensive evaluation are generally small with shallow-root or fibrous root systems, and so they are less destructive and have high retention value [9, 11, 12]. In addition, the

Table 2 Index weights of the comprehensive evaluation system for the Wall-Top Plants

The Constraint Layer	Weights of the Constraint Layer indicators	The Standard Layer	Weights of the Standard Layer indicators	Index Weights of Comprehensive Evaluation
C_1 Biological characteristics	0.239	P_1 Plant type	0.110	0.026
		P_2 Plant diameter /cm	0.108	0.025
		P_3 Plant height /cm	0.069	0.016
		P_4 Growing condition	0.167	0.040
		P_5 Intrusiveness	0.398	0.095
		P_6 Regenerative capacity	0.148	0.035
C_2 Disruptive effects	0.549	P_7 Impact on the near side walls	0.358	0.197
		P_8 Impact on the top surface of the Great Wall	0.235	0.129
		P_9 Influence of encroachment and decay	0.223	0.123
		P_{10} Biological nests	0.183	0.101
C_3 Application value	0.211	P_{11} Historical and cultural value	0.435	0.092
		P_{12} Ecological value	0.296	0.063
		P_{13} Landscape value	0.269	0.057

higher growth density of these plants (per unit area) makes them the dominant species community on the top surface of the Great Wall, and they can form "soft cover" [17, 23]. These native plants can provide protection against weathering, rainwater erosion, and other damage to the top surface of the Great Wall [11, 12, 14]. However, this protection needs further observation as well as experimental verification to ensure its feasibility [23]. In addition to the necessary preservation and protection, the later management of these plants is important. For example, it is necessary to remove some exotic plants such as *Dysphania ambrosioides* (an invasive alien species from tropical America)in time. Furthermore, more attention should be paid to removing herbs near the drainage outlet of the top surface of the Great Wall [4, 12].

2. In the comprehensive evaluation, the biological characteristics of plants in Grade II are more significant than those in Grade I (e.g., larger specifications), and most of the tree and shrub species grow in the middle range of the top surface of the Great Wall. Considering that the damage to the top surface of the Great Wall caused by the plants' root distribution, it is recommended that tree species with low damage impact scores (e.g., *Armeniaca vulgaris*, *Prunus salicina*, *Pyrus betulifolia*, *Vitex negundo* var. *heterophylla*, *Amygdalus davidiana*, and *Ziziphus jujuba*) should be appropriately cleared (retaining the single plant or plant community); and rare and protected plants, such as *Macluratricuspidata*, *Juglans mandshurica*, and *Polygonatum sibiricum*, should be preserved as much as possible strengthen management in the later stage.
3. Plants in Grade III are mainly trees and shrubs in the area of the near side wall, with good growth conditions and well-developed root systems. However, there is a serious threat to the structural safety of thetop surface and the side of the Great Wall in both horizontal and vertical directions (the damage of the Great Wall include side wall skew, hollow structure, and other building issues) [4, 5].

Study limitations

The construction of the Great Wall spanned over thousands of years, and the Great Wall is distributed over a vast area of Northern China, with significant differences in construction at different times and in different regions.

Table 3 Comprehensive evaluation score and grade division of the wall-top plants

Serial number	Species	C_1 Biological characteristics	C_2Disruptive effects	C_3Application value	Comprehensive evaluation	Grade
1	*Clematis fruticosa*	0.931	2.300	0.325	3.556	I
2	*Androsaceumbellata*	0.915	2.300	0.325	3.540	I
3	*Thalictrum petaloideum*	0.851	2.300	0.325	3.476	I
4	*Iris dichotoma*	0.835	2.300	0.325	3.460	I
5	*Leonurus japonicus*	0.931	2.300	0.211	3.443	I
6	*Euphorbia esula*	0.931	2.300	0.211	3.443	I
7	*Artemisia stechmanniana*	0.931	2.300	0.211	3.443	I
8	*Rubia cordifolia*	0.915	2.300	0.211	3.426	I
9	*Acalypha australis*	0.851	2.300	0.211	3.363	I
10	*Crepidiastrum sonchifolium*	0.851	2.300	0.211	3.363	I
11	*Ophiopogon bodinieri*	0.780	2.300	0.211	3.292	I
12	*Spiraea fritschiana*	0.565	2.099	0. 564	3.228	I
13	*Androsace umbellata* (near the side wall)	0.915	1.907	0.325	3.146	I
14	*Bupleurum chinense*	0.590	2.300	0.211	3.101	I
15	*Polygonatum sibiricum*	0.590	2.300	0.211	3.101	I
16	*Polygonatum macropodium*	0.590	2.300	0.211	3.101	I
17	*Dysphania ambrosioides*	0.634	2.300	0.119	3.054	I
18	*Spiraea trilobata*	0.591	1.854	0.564	3.009	I
19	*Deutzia parviflora*	0.840	1.473	0.655	2.968	II
20	*Grewia biloba*	0.511	1.840	0.542	2.894	II
21	*Maclura tricuspidata*	0.398	2.055	0.428	2.881	II
22	*Rhamnus parvifolia*	0.883	1.214	0.747	2.845	II
23	*Vitex negundo* var. *heterophylla*	0.968	0.984	0.873	2.824	II
24	*Polygonatum sibiricum* (near the side wall)	0661	1.907	0.211	2.779	II
25	*Bupleurum chinense* (near the side wall)	0661	1.907	0.211	2.779	II
26	*Lespedeza bicolor*	0.510	1.473	0.634	2.616	II
27	*Ilex crenata*	0.662	1.595	0.337	2.594	II
28	*Prunus salicina*	0.813	0.984	0.689	2.486	II
29	*Juglans mandshurica*	0.543	1.113	0.759	2.416	II
30	*Amygdalus davidiana*	0.543	0.984	0.873	2.400	II
31	*Campylotropis macrocarpa*	0.458	1.473	0.450	2.381	II
32	*Morus australis*	0.745	1.113	0.462	2.320	II
33	*Ziziphus jujuba*	0.543	0.984	0.759	2.286	II
34	*Leptopus chinensis*	0.502	1.214	0.542	2.258	II
35	*Pyrus spp*	0.543	0.984	0.689	2.216	II
36	*Armeniaca vulgaris*	0.543	0.984	0.689	2.216	II
37	*Robinia pseudoacacia*	0.351	1.113	0.597	2.061	II
38	*Morus mongolica*	0.447	1.113	0.462	2.022	II
39	*Deutzia parviflora* (near the side wall)	0.840	0.489	0.655	1.985	III
40	*Vitex negundo* var. *heterophylla* (near the side wall)	0.916	0.101	0.873	1.890	III
41	*Amygdalus davidiana* (near the side wall)	0.543	0.504	0.810	1.857	III
42	*Vitis amurensis*	0.181	0.984	0.575	1.741	III
43	*Armeniaca vulgaris* (near the side wall)	0.543	0.230	0.873	1.646	III

Table 3 (continued)

Serial number	Species	C_1 Biological characteristics	C_2Disruptive effects	C_3Application value	Comprehensive evaluation	Grade
44	*Lespedeza bicolor* (near the side wall)	0.510	0.489	0.634	1.632	III
45	*Campylotropis macrocarpa* (near the side wall)	0.458	0.489	0.450	1.397	III

The conclusions of this article regarding the Dazhuangke Great Wall are only applicable to the Great Wall built in the Ming Dynasty in the Beijing area and to areas with similar natural climates and construction characteristics.

For special conditions (such as special plant species, specifications, and growth location of the Great Wall), it is necessary for experts in the protection and restoration of the Great Wall to make on-site decisions. The principles of "one tree, one discussion, and one policy" and "one section, one discussion, and one policy" should be adhered to as far as possible.

Conclusion

In this article, the construction of the AHP evaluation system, the evaluation process, and the disposal recommendations are applicable to the general situation of the plants on the top surface of the Great Wall. The system can identify the plant species suitable for sustainable coexistence with the Great Wall by comparing each correlation factor layer by layer. In this way, the system can contribute to protecting the integrity of the Great Wall and constructing a sustainable historical and cultural landscape for the Great Wall.

In Grade I, 16 species of herb and two species of shrub do not cause harm to the body of the Great Wall either now or in the future, and these plants should be retained (recommendation of "Preservation") and used as "soft cover" and as a component of the Great Wall's cultural landscape.

Some plants in Grade II have not yet posed a serious threat to the structural safety of the Great Wall because of their locations, and they should be partially retained and managed later (recommendation of "Partial Preservation").

In Grade III, six species of tree and shrub, and the subsequent residual root systems should be removed that have already caused or have the potential to cause harm to the structural safety of the Great Wall (recommendation of "Removal").

The conclusions provide a scientific basis for the protection and protective repair of the Great Wall heritage and the construction of "Garden on the Great Wall."

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Declarations

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