Article

Landscape Visual Sensitivity Assessment of Historic Districts—A Case Study of Wudadao Historic District in Tianjin, China

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Abstract: Against the backdrop of urban stock renewal, as the core area of a city rich in culture, aesthetics, and tourism resources, the assessment of landscape visual sensitivity of historic districts can provide an accurate, objective, and intuitive decision-making basis for the multi-purpose planning of districts. The main purpose of this study was to develop an assessment method based on the geographic information system (GIS) in order to make a visual sensitivity index map on a district scale. To this end, this study uses the multi-criteria evaluation (MCE) method, selects the visibility (VS_v), the number of potential users (VS_u), and remarkableness (VS_e) as the main criteria, and constructs a comprehensive assessment model of the visual sensitivity of the historic landscape. The most well-protected Wudadao Historic District in Tianjin (Wudadao) was selected as the study area, and its visual sensitivity was assessed. The assessment results are divided into four levels: areas of high sensitivity, moderate sensitivity, low sensitivity, and very low sensitivity. Results indicate that after the optimization and improvement of the evaluation index for visual sensitivity of a large-scale forest landscape, it is feasible to evaluate the small-scale visual sensitivity of historic districts; the higher the sensitivity level, the more important it is to be protected, and the more cautious it should be in the renewal of districts; the higher the number of potential users, the higher the visual sensitivity level, and so on. Further attention needs to be paid to planning and design to improve visual quality.

Keywords: historic district landscape; visual sensitivity; landscape assessment; Wudadao

1. Introduction

After the fast-paced spread of the city, the development mode began to change from "incremental expansion" to "stock renewal" [1]. Urban renewal has become an important issue in urban planning and management. Historic districts, as a typical representative of the sensitive area with high cultural value and high vulnerability in the city, are in urgent need to be properly protected and organically renewed. At the same time, historic districts are an indispensable part of the city to show its charm, as they are the source of the gene to develop the city's personality in a sustainable way. Protecting and building a high-quality visual environment of the historic districts landscape can better show the city's historical context and characteristics to the public, so as to enhance the city's recognition among people and their sense of place and avoid presenting similar landscapes in all cities [2]. Therefore, it is essential to carry out a quantitative assessment of the visual sensitivity of the landscape of historic districts and take its results as the basis for the landscape protection and construction planning of the historic districts. This step is an indispensable part of implementing a more prudent, meticulous, and progressive renewal strategy and improving the quality of the visual environment.

In order to more objectively evaluate the impact of human activities on the visual quality of a landscape, based on the possibility of human perceptions of people's distur-

bance effects on a landscape, Litton (1974) proposed the concept of visual vulnerability, which refers to the resilience and susceptibility levels of a landscape in response to the disturbances caused by human activities and natural environment changes [3,4]. In city planning, the concept of landscape visual sensitivity is often defined as the resilience or fragility of the historic district landscape to changes, such as city construction activities [5]. Visual sensitivity assessment of the landscape environment can provide location information of the most sensitive area of historic districts in terms of visual change [6]. As a necessary factor to evaluate the landscape visual quality [7], the sensitivity of landscape reflects the response ability and tolerance of the landscape to external interference [8], but it also shows the degree to which the landscape is noticed [9]. The higher the degree of the attention, the higher the visual sensitivity of the landscape, and the greater the response of the landscape to disturbances caused by external changes [10]. In areas with high visual sensitivity, even slight changes may be easily detected by the viewer, so it should be taken as a key protection area [9].

The research on landscape visual sensitivity assessment began in the 1960s in Western developed countries [11]. In the 1960s–1980s, with the promulgation of laws and regulations aimed at protecting landscape visual resources in various countries [12,13], the establishment of various visual resource management systems [14–16], and the accumulation of a large number of research literature [17,18], the basic research paradigm of landscape visual sensitivity assessment was established [11]. These research results have had a lasting and far-reaching impact in the field of landscape visual sensitivity assessment and are still the focus of landscape planners' work [11]. Since the 1980s, many scholars worldwide have evaluated the landscape visual sensitivity of different scales [6,19], regions, and types [20,21] on the basis of previous studies. The assessment results have been widely used in landscape visual impact assessment [22], landscape character assessment [23], environmental resource management [24], ecotourism suitability assessment [25], ecological restoration and protection decisions [20], etc. Despite these research results, the methods and principles of landscape visual sensitivity assessment have made little progress [26], and the research focuses on the continuous improvement and verification of evaluation standards and integration with computer technology [8,9,20,27]. In terms of evaluation methods, field investigation methods [27,28], expert evaluation methods [6,8], multi-criteria evaluation (MCE) methods [8,29], analytic hierarchy processes (AHPs) [6,29], and conjunction and disjunction methods [9,20] are mostly used. In terms of evaluation data, municipal information data, digital elevation models (DEMs), and other traditional data are often used [6,8] In the era of big data, the utilization of rich open network data is obviously insufficient. In terms of evaluation scale, the large-scale natural landscape is mainly evaluated [6,27]. A few studies have involved urban areas [20,30], and the research on historic districts is rare [31,32]. To sum up, the research on the landscape visual sensitivity of small-scale and distinctive historic districts clearly lags behind the actual needs for their renewal.

Wudadao has survived many major historical changes and the Tangshan earthquake in 1976 [33]. With the unremitting efforts of the government and planners, it has become the most well-preserved and distinctive historic district in Tianjin, and it is like a history book inviting people to read today [33]. As a cultural source of the sustainable development of Tianjin city, its protection and renewal work will continue, so that it can truly integrate into city life and continue to increase the vitality of the district; however, the local government and planning department have not paid enough attention to the visual sensitivity assessment of Wudadao. Therefore, in this study, Wudadao was taken as the study area, and the MCE based on geographic information system (GIS) was used to build a landscape visual sensitivity assessment model. By using more simple and efficient combination and disjunction methods, the results of the main criteria and sub-criteria are calculated, and a comprehensive map of the landscape visual sensitivity of Wudadao is drawn. Our results can provide a more scientific and objective decision-making basis for the future planning and construction of historic districts.

2. Materials and Methods

2.1. Study Area

Wudadao is located in the Heping District and the Hexi District of Downtown Tianjin, with a total planning area of 1.917 km^2 and a planning area of 1.2 km^2 for the core reserve (Figure 1). The district is generally shaped in a rectangular grid, including five street profiles with a width of 100–500 m divided by six east–west roads and six street profiles with a length of 100–300 m divided by seven north–south roads. There are 14 historic districts in Tianjin, of which Wudadao is the largest and best preserved. It was founded in 1901, and it formed a high-end residential area in the British Concession in the 1930s, which was composed of today's Machang Road, Munan Road, Dali Road, Changde Road, Chongqing Road, and Chengdu Road. This district, which has former celebrity residences, is the specific result of the British Garden City Theory in China in the early 20th century [34]. The curving grid road network and the continuous and changeable space of streets and alleys together constitute the spatial pattern of a small street outline and a dense road network. The total number of existing buildings in the district is 2514. The buildings are mainly residential and office buildings, supplemented by comprehensive experiential services such as leisure and entertainment, hotels, and catering. Among them, most of the historic buildings are Western-Style houses with garden villas, which are composed of small, two- to three-story Western-Style buildings. The living rooms, facing the streets, are separated from the courtyard, and the courtyard walls stand among the flowers and trees inside and outside. The atmosphere of the district is elegant and quiet with strong privacy. Due to its unique historic buildings and urban texture, Wudadao has become a historic district characterized by the architecture of "Tianjin Western-Style Buildings" [34,35].
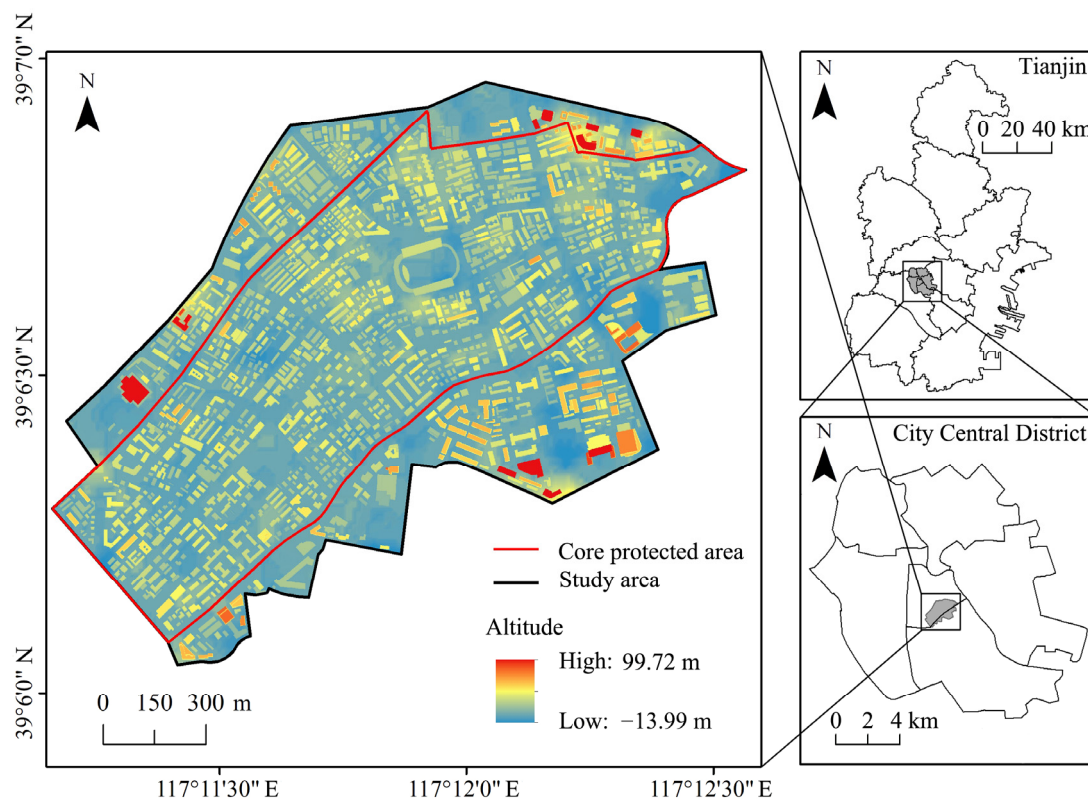

Figure 1. Case study area and geographic location of the Tianjin central district (Altitude refers to the heights of the buildings in relation to the ground level).

2.2. Preparation of the Data

The data used in this study were obtained via the three following ways. (1) Data obtained from the government official websites and the relevant planning documents include the administrative division of Tianjin, the protection planning scope of the Wudadao historic district and building contour vector data with floor attribute information from the Tianjin Municipal Bureau of Planning and Natural Resources, as well as basic information on Tianjin's historic buildings through the unified open platform website of Tianjin's information resources (Available online: https://data.tj.gov.cn; accessed on 22 November 2020); (2) Data obtained from commercial channel include a DEM of Tianjin with a 12.5 m accuracy from Suzhou Zhongke tuxin network (Available online: https://www.tuxingis.com; accessed on 21 April 2020). (3) Open source data include point of interest (POI) data of Tianjin based on AMAP (the web map of AMAP; Available online: https://www.amap.com; accessed on 22 April 2020) in 2019, vector municipal road data from OpenStreetMap (Available online: https://www.openstreetmap.org; accessed on 22 April 2020), and data collected through the Dianping website with attribute information, such as shop or scenic spot names, addresses, and the total number of comments (crowd sourcing geographic data website; Available online: https://www.dianping.com; accessed on 22 May 2020).

The evaluation criteria were calculated using the tools of ArcGIS software (Esri, V10.4). In the process of calculation, the resolution of a raster map was unified at 0.2 m × 0.2 m. Google high-definition images, field research, and related text materials were obtained, and data sorting and cleaning and screening work were performed. DEM and building contour vector data were used to construct a grid surface with buildings in the study area, namely an urban digital elevation model (UDEM) [30], which is the three-dimensional model for spatial analysis in this study (Figure 2).
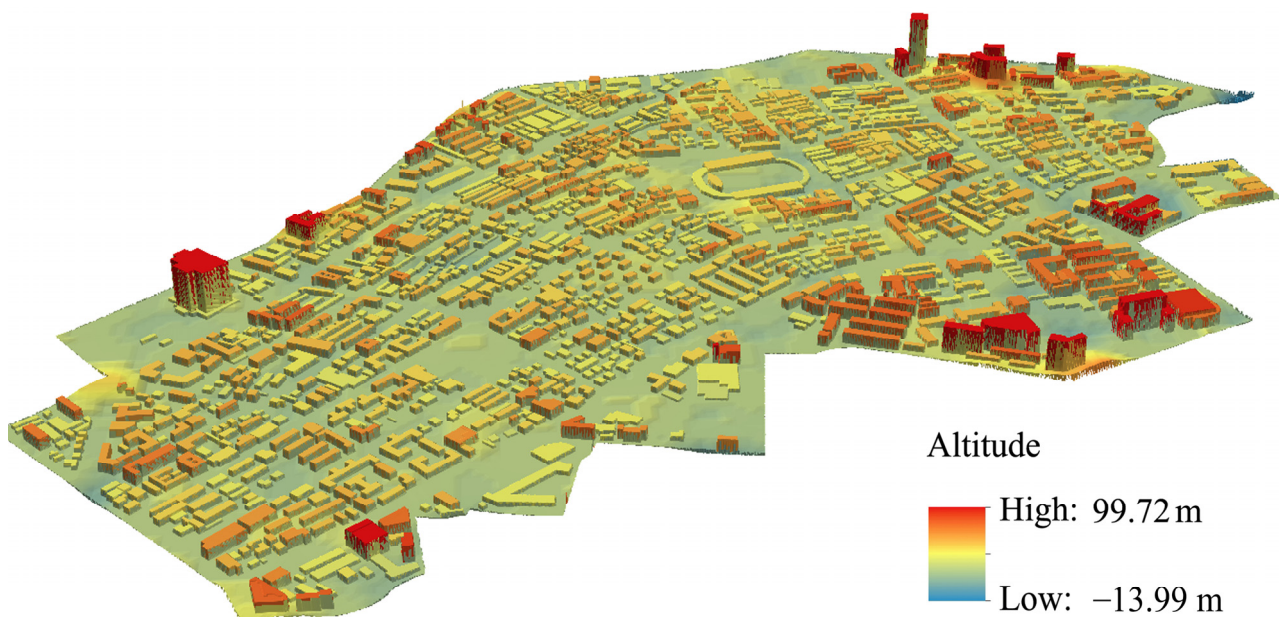

Figure 2. The urban digital elevation model (UDEM) of the study area (Wudadao).

2.3. Determination of the Visual Sensitivity Creteria

The visual sensitivity of a landscape is a comprehensive reflection of the visibility, clarity, remarkableness, and the interaction between the viewer and the landscape. It is often closely affected by factors such as the spatial location of the landscape, physical attributes, and the relative position of a person and the landscape [9]. Throughout the relevant research at home and abroad, although the terms, variables, objectives, and methods used in landscape visual sensitivity assessment are varied, the key concepts include (1) the visibility and distance interval from the observation point, (2) types and

amount of use, (3) landscape attraction and quality, and (4) viewers' experiences [29]. Based on early research results and other existing knowledge, we used multi-source open data and selected three common indicators, i.e., visibility, the number of potential users, and remarkableness, as the main criteria to build the landscape visual sensitivity evaluation model. Each main criterion consists of sub-criteria. Based on Wudadao, using the constructed landscape visual sensitivity assessment model (Figure 3), the calculation results of all levels of assessment criteria were graded, assigned, and superimposed to evaluate the comprehensive visual sensitivity of Wudadao (Table 1).
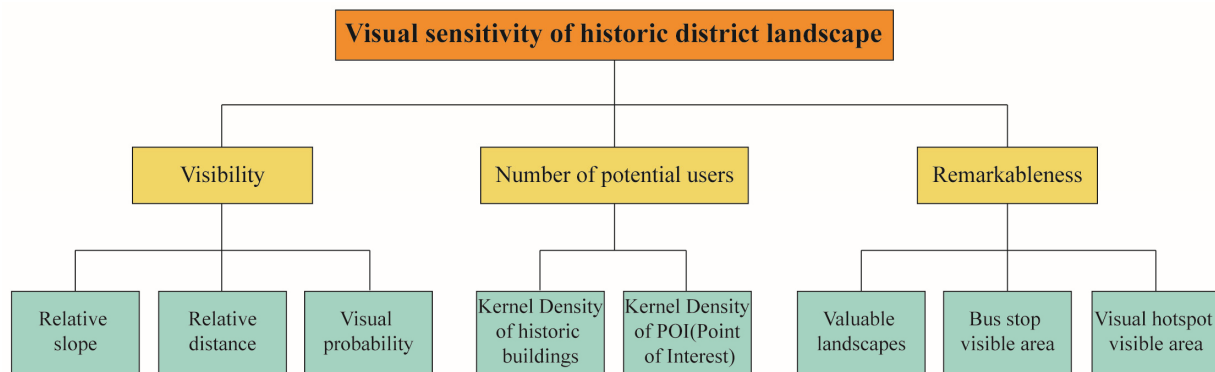

Figure 3. The hierarchy of the landscape visual sensitivity assessment model of Wudadao.

Table 1. Classification and assignment of the landscape visual sensitivity assessment criterion.

Criterion		Levels of Visual Sensitivity			
Main-Criterion	**Sub-Criterion**	**High (Score: 7 Points)**	**Moderate (Score: 5 Points)**	**Low (Score: 3 Points)**	**Very Low (Score: 1 Point)**
Visibility (VS_v)	Relative slope (S_a)	$S_a > \sin45°$	$\sin15° < S_a \leq \sin45°$	$\sin8° < S_a \leq \sin15°$	$\sin0° \leq S_a \leq \sin8°$
	Relative distance (S_d)	$S_d = 1$ ($d \leq 25$ m)	$1 > S_d > 1/2$ (25 m > $d \geq 50$ m)	$1/2 \geq S_d > 1/4$ ($100 \geq d > 50$ m)	$1/4 \geq S_d$ ($d > 100$ m)
	Visual probability (S_t)	243–56	55–10	9–1	0
Number of potential users (VS_u)	Kernel density of historic buildings (S_b)	820–463	462–296	295–132	131–0
	Kernel density of POI (S_p)	13,014–5971	5970–3164	3163–1736	1735–0
Remarkableness (VS_e)	The valuable landscapes, the visible area within 100 m of the bus stations, and the visible area within 100 m of the visual hotspots are all regarded as high-level visually sensitive areas.				

2.3.1. Visibility (VS$_v$)

In the study of visual sensitivity, it is very important to determine which landscape elements can be seen or can be seen more clearly. Visibility in this study refers to whether the landscape elements of historic districts can be seen, their clarity, and the probability that they are seen (visual probability). The main visibility criteria of the historic district landscape are divided into three sub-criteria: relative slope, relative distance, and visual probability. The closer the landscape elements are to the viewpoint, the higher the frequency of them being seen. Therefore, the higher the visibility, the higher the visual sensitivity [36,37].

- Relative Slope (S_a).

As the slope of the landscape surface relative to the viewer's line of sight increases, the location of the landscape and the possibility of being noticed increases, and so does the visual impact of human activities in the area on the landscape. Therefore, the projected area of the landscape surface along the line of sight can be used to measure the landscape visual sensitivity [9]. If the landscape surface area is set to 1, the projection area—the calculation formula of landscape visual sensitivity based on the relative slope—is as follows [9,20]:

$$S_a = \sin(\alpha) \quad (0° \leq \alpha \leq 90°) \tag{1}$$

where α is the angle of the landscape surface relative to the viewer's sightline, and S_a represents the total projected area of the viewshed. The larger the α, the greater the landscape visual sensitivity. When the landscape surface is perpendicular to the line of sight ($\alpha = 90°$), the projection area of the landscape is the largest, and the value of S_a is the largest ($S_a = 1$). When the landscape surface is parallel to the line of sight ($\alpha = 0°$), the projection area of the landscape is the smallest, and the value of S_a is the smallest ($S_a = 0$). The value range of S_a is 0–1.

In order to facilitate the assessment, it is necessary to grade the slope results according to certain standards. At present, the method of slope analysis based on GIS technology combined with DEM data source for ground information extraction is very mature, and a slope classification system decides whether slope analysis is effective and scientific. The classification methods of slope mainly include a commonly subjective classification method, a critical classification method, and a mode classification method [38]. Each of the three methods has its own advantages and disadvantages. Researchers need to select the most scientific and effective classification method according to the geomorphic characteristics and application purpose of the study area. For the classification of relative slope, different institutions and scholars adopt different classification standards according to the characteristics of the study area [9,20,39].

The UDEM based on Wudadao calculates the relative slope using the slope analysis tool of ArcMap. The area with the relative slope of sin30°–sin60° is the smallest. Therefore, in the flat slope and gentle slope area, the smaller span range is selected for segmenting. The relative slope (sinα > 45°) formed by most buildings and the ground surface is similar to the steepness of the cliff slope. The relative slope is larger and occupies less area. The value range of the larger relative slope is wider. Therefore, referring to the slope classification standard of the existing research results, combined with the slope characteristics of the region reflected by the slope critical value obtained by the Jenks natural breaks in the model classification method, the relative slope was divided into four grades (Table 1).

- Relative Distance (S_d).

The viewing area of the historic district is mainly located in areas that can be reached by viewers, such as the roads at all levels of the district. Districts landscape, being closer than roads, have more visibility and clarity; the higher the landscape visual sensitivity, the greater the visual interference caused by human activities. If the maximum distance needed to clearly see a certain landscape element, texture, or component is D, and the actual distance of the landscape relative to the viewer is d, the landscape visual sensitivity (S_d) based on the relative distance can be obtained according to the following formula:

$$S_d = \begin{cases} 1 & \text{if } d \leq D \\ \frac{D}{d} & \text{if } d > D \end{cases} \tag{2}$$

when $d \leq D$, the viewer can see the details of the district landscape, and the landscape visual sensitivity takes a maximum value—in this case, $S_d = 1$. When $d > D$, the landscape visual sensitivity decreases with the increase of d until the landscape cannot be seen—$S_d = 0$. In this case, the value range of S_d is $0 \leq S_d < 1$. The value of D can be set according to the landscape and terrain characteristics of the study area and different accuracy requirements.

Based on the visual characteristics of human eyes, combined with the actual landscape characteristics of "a narrow street outline, a dense road network," and a road grade and width, the value of D was set to 25 m. S_d = 1, 1/2, and 1/4 were taken as the dividing limits of the distance zone. The Euclidean distance tool of ArcMap was used to calculate the Euclidean distance along the road centerline of Wudadao. Using the reclassify tool, S_d was then divided into four grades according to the actual distance along the road centerline.

- Visual Probability (S_t).

Within the scope of the viewer's vision, the longer the landscape lasts or the greater the probability of occurrence, the higher the landscape visual sensitivity, and the greater the probability that human activities will interfere with the landscape [9,22]. In the part of visual sensitivity evaluation of the Jiufeng Urban Forest Reserve in Wuhan, Qin et al. (2009) used the percentage of the length of the main viewing line to calculate the visual probability [28]. Wang et al. (2018), based on the UDEM data, using the cumulative viewshed method and the viewshed tool of ArcMap, calculated the cumulative visual amount of urban district landscape and divided the results into three levels: high, medium, and low [30]. Zheng et al. (2019) used the visibility analytical tool in ArcMap to calculate the probability of visible frequency of forest cells obtained from each viewpoint [20]. Based on the previous research results, we set one viewpoint every 30–50 m along the centerline of Wudadao and obtained 540 viewpoints. Based on these viewpoints, the number of times each cell of Wudadao is seen by the viewpoint is calculated by using the viewshed tool of ArcMap. The more times each cell is seen by the viewpoint, the higher the visual probability, that is, the higher the visual sensitivity. The highest visible frequency of a given landscape unit was estimated to be 243, and the lowest was 0 (not visible). Then, the calculation results were divided into four grades according to the Jenks natural breaks method, which is based on the Jenks' Natural Breaks algorithm (Table 1).

2.3.2. Number of Potential Users (VS_u)

Although it is impossible to determine the actual amount of users, the second main criterion can be used to estimate and infer the relative number of potential users [8]. The criterion of the number of potential users consists of two sub-criteria: the Kernel Density of historic buildings and the Kernel Density of POI. The higher the Kernel Density of historic buildings and POI, the greater the attraction to users, and the higher the visual sensitivity of landscape.

1. Kernel Density of Historic Buildings (S_b).

Architecture is an important element of the landscape of the historic district, and it is an important material carrier to carry the historical and humanistic genes of the district. Among them, the higher the density of historic buildings, the higher the aesthetic quality of a district landscape, and the higher the attraction of a district landscape. This also often indicates that the number of potential local residents and foreign tourists will increase. Therefore, the study firstly used "Add XY Date" function of ArcMap to convert each building into point feature data based on its latitude and longitude coordinates; then, it used the ArcMap Kernel Density tool to calculate the density value of historic buildings in each cell of the study area. Finally, the Jenks natural breaks method was used to divide the results into four grades (Table 1).

2. Kernel Density of POI (S_p).

The more attractive historic districts tend to have a more pleasant spatial scale and a more profound culture and heritage. The vibrant and diversified distribution and pattern of public infrastructure and commercial formats are also effective factors in acquiring more potential users [40]. As a new spatial data source, POI data, which contain abundant information of public infrastructure and commercial formats, are characterized by a large volume, wide coverage, high recognition accuracy, and easy access. Overcoming the disadvantages of traditional data, it has the characteristics of up-to-dateness, accuracy,

sharability, and multi-classification, which are of great significance in research on landscape visual sensitivity assessment [41]. It has been reported that POI, basic data for urban spatial analysis, intuitively and effectively reflects the agglomeration of various urban elements. The density of point feature data can be estimated with high quality by Kernel Density Estimation, which is independent of the size and location of cells [42] In this study, the density distribution of a diversified public infrastructure and commercial outlets in Wudadao was analyzed using the ArcMap Kernel Density tool based on POI data. Then, the results were divided into four levels according to the Jenks natural breaks method (Table 1).

2.3.3. Remarkableness (VS_e)

The remarkableness of landscape is an important factor to determine the visual sensitivity of a historic district. Landscape remarkableness mainly depends on the contrast between landscape and environment, such as the contrast of district landscape elements in shape, color, movement, and so on [9]. For historic districts, areas with high remarkableness also include recognized valuable landscapes, such as areas with specific labels given by the government, famous scenic spots designated in urban planning documents, and planning core and hot spots [9]. In addition, the area near the bus station and the visual hotspot area analyzed by Dianping data are also areas with high visual sensitivity. The Dianping data used in this study are the cumulative total number of comments of each scenic spot or shop on the website since its establishment. The data have certain stability and timeliness, which can be used to analyze and locate visual hotspots.

First of all, according to the documents of the Conservation Planning of Wudadao Historic Area, combined with field research and GPS positioning technology, we illustrated the area and boundaries of valuable scenic spots. Secondly, through the information and location of bus stops provided by POI data, combined with field research, the accurate number and specific locations of bus stops were obtained. The third step was to use the CreateFishnet tool to count the total number of reviews of all stores in each 50 m × 50 m grid and divide the calculation results into five levels by using the Jenks natural breaks method for visual display. According to the visual results of the post comment hotspots, combined with the information on planning hot spots and key scenic spots, 10 visual hotspots were selected as the visual hotspots (Figure 4).
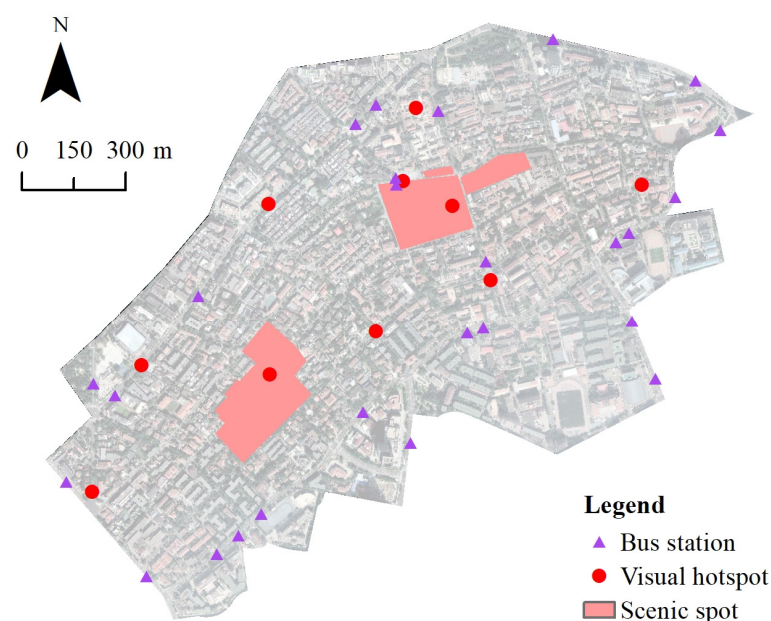

Figure 4. Bus stations, visual hotspots, and scenic spots.

In addition, the remarkableness of the visible area was higher than that of the invisible area. The probability and remarkableness degree of the bus stops and the selected visual

hotspots in the study area were higher than those of the other visible areas. Therefore, combined with the characteristics of human visual perception and the results of viewshed analysis along the roads, a distance of 100 m, over which a human can see a landscape structure, was selected as the segmentation value for high visual sensitivity areas. Then, the buffer tool of ArcMap was used to make a 100 m buffer for each bus stop and visual hotspot, and the visual field of each bus stop and visual hotspot was calculated with the viewshed tool. Finally, the valuable landscapes, the visible area within 100 m of the bus stop, and the visible area within 100 m of the visual hotspot were superimposed according to the principle of maximum value, and the superimposed area was regarded as a high-level visually sensitive area (Table 1).

2.4. Comprehensive Visual Sensitivity

The visibility (VS_v), the number of potential users (VS_u), and remarkableness (VS_e) are the three main criteria used, which often interact and jointly affect the visual sensitivity of the historic district landscape. These main assessment criteria have similar importance in determining visual sensitivity [8]. The comprehensive visual sensitivity (VS) of historic districts is a function of the sensitivity of each component of the assessment based on a single criterion, which can be expressed by the following formula [9,20]:

$$VS = f(VS_v, VS_u, VS_e). \tag{3}$$

The three main assessment criteria are divided into several sub-criteria, so it is necessary to calculate the classification and distribution of the sub-criteria to obtain the final comprehensive visual sensitivity level and spatial distribution results. Firstly, according to the classification results of the relative slope, relative distance, visual probability, Kernel Density of historic buildings, Kernel Density of POI, and remarkableness, the reclassify tool of ArcMap was used to assign 7 points, 5 points, 3 points, and 1 point according to the visual sensitivity level from high to very low, and a corresponding visual sensitivity assessment level map was illustrated (Table 1). Formula (4) was used to stack the sensitivity results of the sub-criteria.

$$VS = (S_a \wedge S_d \wedge S_t) \vee (S_p \vee S_b) \vee VS_e \tag{4}$$

The process of superposition is actually the conjunction of the three sub-criteria of visibility ($\wedge$) and the disjunction of the number of potential users and the remarkableness ($\vee$). After obtaining the visual sensitivity results of the three main assessment criteria, the three criteria are conjoined to obtain the final overall visual sensitivity indicator. The calculation process is shown in Formula (5):

$$VS = VS_v \vee VS_u \vee VS_e. \tag{5}$$

The superposition process of visual sensitivity results at all levels based on the main and sub-criteria can be regarded as the process of taking the minimum and maximum values. Therefore, the overall visual sensitivity indicator of historic districts can also be superimposed according to Formula (6) to calculate the most likely visual sensitivity of each cell in the study area. Thus, the results are divided into four levels: high sensitivity, moderate sensitivity, low sensitivity, and very low sensitivity.

$$VS = max\left[min(S_a, S_d, S_t), (S_p, S_b), VS_e\right] \tag{6}$$

3. Results

3.1. Sensitivity of Visibility

Using the reclassify tool in ArcMap, the calculation results of relative slope, relative distance, and visual probability were reclassified and assigned values, and a visual sensitivity thematic map of the three sub-criteria under the main assessment criteria of visibility

was drawn (Figure 5a–c). As shown in Figure 5a, according to the visual sensitivity classification results based on the relative slope, the terrain of Wudadao is gentle, with a large area of a $\sin 0° \leq S_a \leq \sin 8°$ flat slope and gentle slope, accounting for 88% of the total area of Wudadao. The other three grades occupy less area. Among them, the area with $\sin \alpha > 45°$ formed by the building and the ground is the largest, which only accounts for 0.03% of the total area of Wudadao, but the visual sensitivity is the highest. Figure 5b is the result of sensitivity classification based on relative distance. The most sensitive area ($d \leq 25$ m), which is closest to the center line of all levels of roads, accounts for 50%. The area of medium sensitivity (50 m $\geq d >$ 25 m) accounted for 33%. Figure 5c shows the classification and distribution of the four visual probability levels of Wudadao. The high visual probability areas are the high-rise buildings in the northeast corner and the People's Stadium in the southwest corner. Although this part of the area accounts for a small proportion, the visual probability is the highest. The areas with moderate visual probability were Tushan Park, Munan Garden, Minyuan bus station, and road intersection, accounting for 16%. The area with low vision probability is the area along the road, accounting for 41%. The remaining area is the invisible area with low visual probability, accounting for 43%.
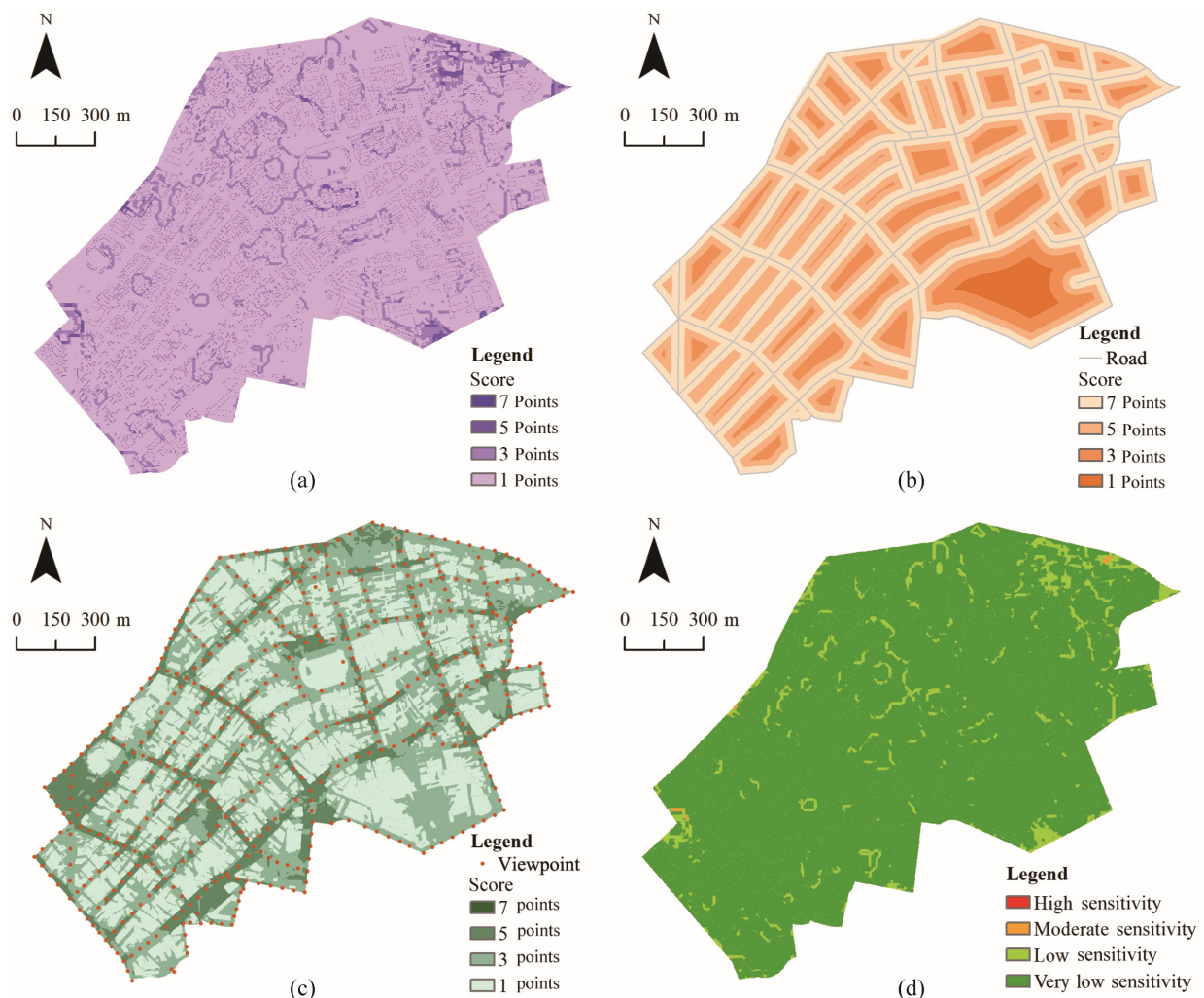

Figure 5. The visual sensitivity based on visibility: (**a**) relative slope-based sensitivity criterion; (**b**) relative distance-based sensitivity criterion; (**c**) visual probability-based sensitivity criterion; (**d**) classification and distribution of visibility visual sensitivity.

Figure 5d describes the comprehensive superposition result after taking the minimum value of the visual sensitivity of the three sub-criteria of relative slope, relative distance, and visual probability according to Formula (6), that is, the visual sensitivity classification

and distribution map based on the visibility criterion. The results show that the area with high visible sensitivity is located in several high-rise buildings, such as the Gangao buildings at the boundary of the core reserve in the northeast of Wudadao. The moderate visible sensitivity area is the visible building facade in the relatively open part of Wudadao. The low visible area is located in the open area at the boundary of Wudadao. The largest proportion is a very low area, accounting for 92% of the total area. It can be seen that although the area of the high-rise building at the boundary of the study area accounts for a small proportion, its visibility and visual sensitivity are very high, and its visual impact on the observer is also very strong. Therefore, in the future planning and renewal strategy of historic districts, we should be very cautious about the construction of high-rise buildings at the boundary of historic districts. The landscape design of parks, gymnasiums, and other public places as well as open areas should also be given enough attention to continuously improve the visual quality of these areas.

3.2. Sensitivity of the Number of Potential Users

As can be seen in Figure 6a, the areas with a high Kernel Density of historic buildings are all located in the core protection area of Wudadao, and the Kernel Density level of construction control areas outside the core protection area is generally low. The analysis results of Figure 6b show that the areas with a high kernel density of POI are mainly located at the junction of the construction control area, the core protection area, and the construction control area. From the aspect of orientation, the POI kernel density in the north of Wudadao is larger than that in the south. The results of kernel density based on historic districts and POI are superimposed by Formula (6) after taking the maximum value, that is, the sensitivity result of the number of potential users, as shown in Figure 7. Through the visual sensitivity calculation of the number of potential users, it is found that the most sensitive area does not appear in previous planning, such as Minyuan Stadium, Munan Garden, and other hot areas. A historic district contains rich human resources and a large number of historic buildings, which is an important carrier of tangible and intangible resources that attract tourists and local residents to visit. Therefore, in order to improve the number of potential users and the vitality of the core reserve of historic districts, while protecting and making good use of historic building resources, it is necessary to continuously optimize the distribution and pattern of public infrastructure and commercial formats and improve user experience.
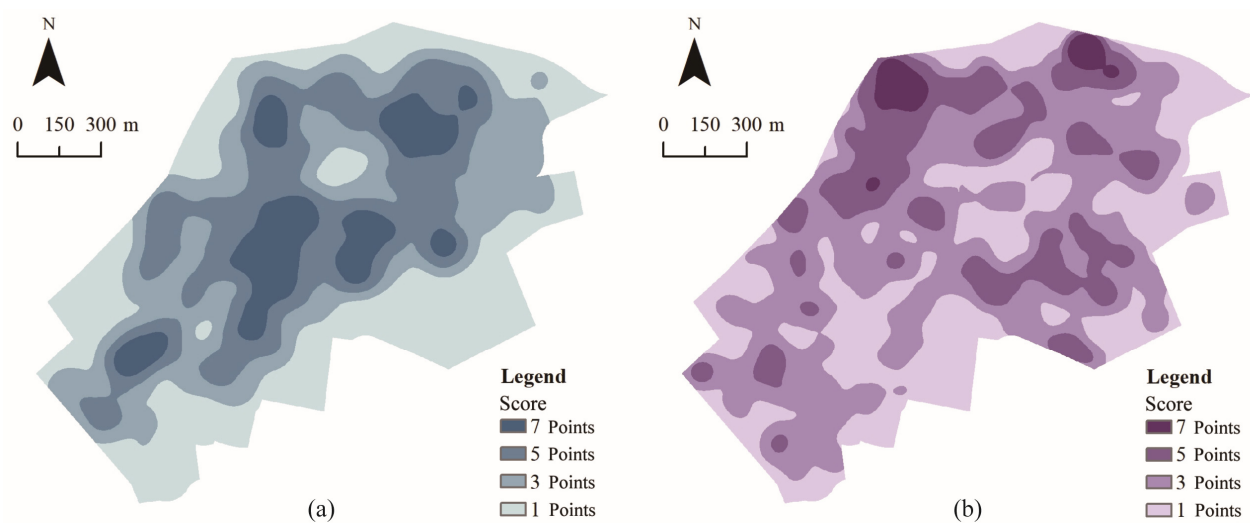

Figure 6. (**a**) Kernel Density of historic-building-based sensitivity criteria; (**b**) Kernel Density of point of interest (POI)-based sensitivity criteria.
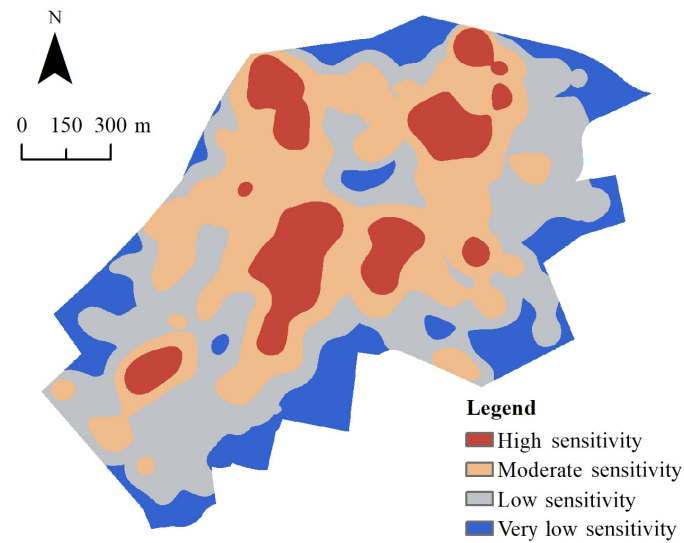
Figure 7. Classification and distribution of the number of potential user visual sensitivity.

3.3. Sensitivity of Remarkableness

By overlapping the attractive areas, such as valuable landscapes, visible areas within 100 m of bus stops, and visible areas within 100 m of visual hotspots, the areas thus formed are all regarded as high-level visually sensitive areas with the main criterion of remarkableness. As shown in Figure 8, the areas with high visual sensitivity are located near public activity spaces such as Minyuan Stadium, Munan Garden, and Tushan Park, as well as the areas at the boundary of the historic district of Wudadao, the junction of the planning core reserve, and the planning control area. The high visual sensitivity area based on saliency accounted for 17% of the total area of Wudadao. These areas are assigned seven points for the superposition of the final main standard assessment results.
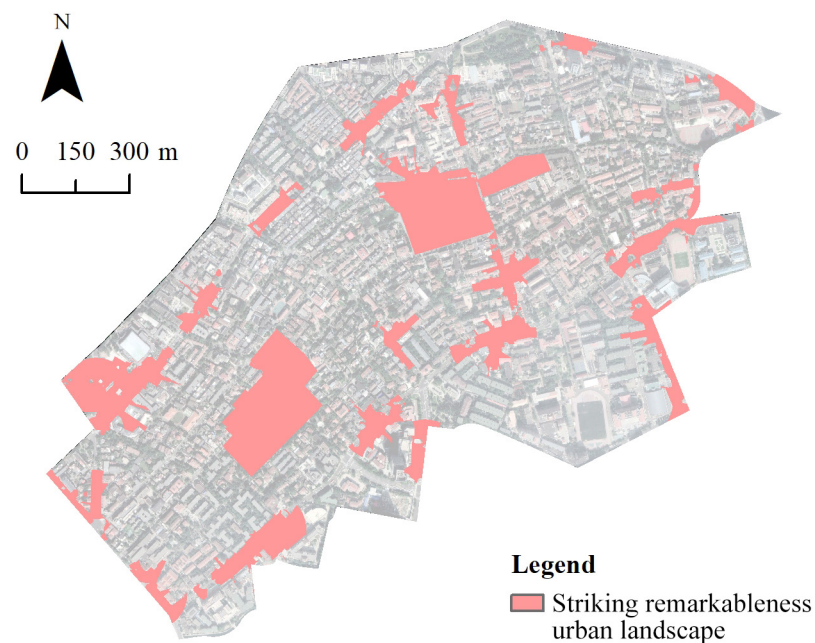

Figure 8. Distribution of remarkable urban landscape.

3.4. Comprehensive Assessment

Figure 9 shows the final synthetic map of landscape visual sensitivity after the superposition of the three main assessment criteria of visibility, the number of potential users, and remarkableness using Formula (6), which reflects the spatial distribution of four

grades of landscape visual sensitivity of Wudadao (Figure 9 and Table 2). The total area of high visual sensitivity is 564,697.32 m², accounting for 29.3% of the total area of Wudadao. This area is mainly concentrated in the core reserve, mainly including the following types: (1) development hotspots in the planning areas, such as Minyuan Stadium, Munan Garden, the QingWang mansion, and other famous scenic spots; (2) areas near the planning and development nodes such as Hebei Road and Guilin Road; and (3) schools, bus stops, visual hotspots, gymnasiums, parks, historic buildings, and POI-intensive areas, which also have high visual sensitivity. In the Wudadao study area as a whole, the visual sensitivity shows an overall decreasing trend from the center to the outside. The very low sensitivity area is mainly located in the planning control area, with the smallest area proportion.
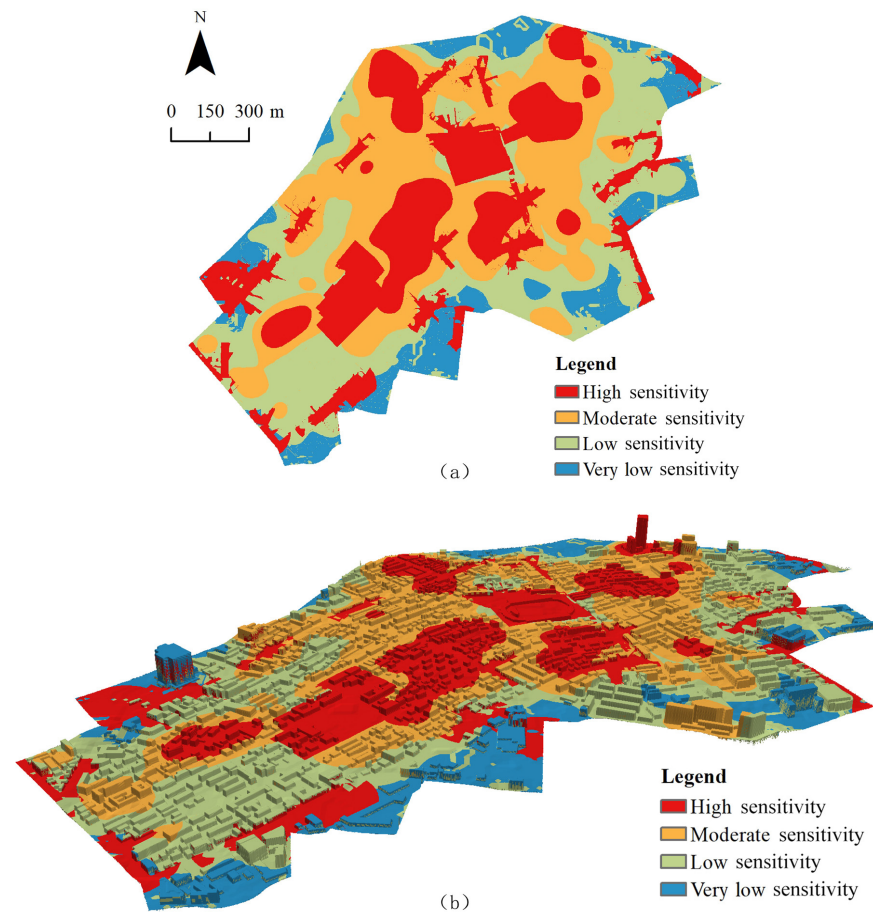

Figure 9. The visual sensitivity of the Wudadao historic district: (**a**) plan view; (**b**) 3D rendering.

Table 2. Classification of landscape visual sensitivity composite index.

Levels of Visual Sensitivity	Area (m²)	Percentage (%)
High	564,697.32	29.3%
Moderate	586,289.88	30.5%
Low	552,050.16	28.7%
Very low	221,212.56	11.5%

Through this study, we found that the landscape of the core protection area with high visual sensitivity should be given priority protection and careful renewal. The area with perfect public facilities and commercial formats is also more sensitive, so we can further improve the vitality of the core protection area of the historic district by increasing its density and optimizing its layout. At present, most of the historic buildings of the former residences of celebrities on Wudadao are for residential and office use, and the frequency

of opening or setting up exhibition contents for tourists is not high. We should make full use of the important cultural tourism resources such as the small- and medium-sized Western-style buildings in Wudadao and the former residences of celebrities. By opening more former residences of celebrities and improving the accessibility of historic districts, the number of potential users in visually insensitive areas will be increased. The strategy of small-scale and gradual "micro renewal" is adopted to promote historic districts, integrate them into urban life, and rejuvenate their vitality. Therefore, it can not only serve as a carrier of continuity in the urban context but can also become a source of the sustainable growth of urban culture.

4. Discussion

In this paper, a comprehensive assessment method of visual sensitivity of historic landscape is presented based on GIS technology. Building on the previous research methods, this study explored, improved, and innovated the type, scale, and assessment criterion of the research area of landscape visual sensitivity. First, the study area selected for the previous research on visual sensitivity is mainly forest landscape area, the type being rather simple, while this study selects the assessment object of the landscape visual sensitivity on the urban historic district rich in historical context. Second, previous research methods are often applied to larger research scales, and small and medium-scale visual sensitivity research is rather weak in this field. This study explores the feasibility of optimizing the common assessment criteria of the visual sensitivity of large-scale forest or urban landscapes for the visual sensitivity assessment of small- and medium-scale areas such as historic districts. Third, the assessment criteria selected in the past research are not closely integrated with the emerging open-source data. Different from the previous assessment model based on relative slope, relative distance, visual probability, valuable landscape, and other assessment criteria, we added historic building information, POI, Dianping, and other open network data to the sub-criteria. The number of potential users criterion, which is composed of historic building kernel density and POI kernel density, can be more regionally targeted than the previous assessment criterion for natural or urban landscapes, and the results obtained are more timely. While doing an objective assessment of historic districts, through the addition of Dianping data, the subjective assessment factors of the public are integrated into the assessment model. Through the addition of these indicators, the feasibility of combining subjective and objective assessment factors, traditional data, and open network data for visual sensitivity assessment is explored.

Through the comprehensive assessment results of visual sensitivity (Figure 9), it can be seen that the high sensitivity area of the Wudadao research area is consistent with the development hot spots and node areas planned by the planning department. In addition to the previously planned hot areas, according to the analysis results, the areas with high visual sensitivity also include historic buildings intensive areas, POI intensive areas, comment hot areas, areas near public transport stations, parks, gymnasiums, schools, and other areas. These areas should also be paid attention to by planning departments. The visual aesthetic quality of these hot spots will affect the psychological and behavioral experience of tourists. Through field investigation, it was found that the visual quality of the district environment in these areas located at the boundary of Wudadao is not satisfactory. Therefore, we need to protect and update the core protected areas and, at the same time, through fine landscape design and management, improve the visual aesthetic quality of the areas at the boundary of the research area, so as to attract more potential users. The highest proportion of areas with moderate visual sensitivity is 30.5%. These areas are basically within the core planning scope of Wudadao, closely surrounding the areas with high visual sensitivity. Changsha Road, Zhijiang Road, and Chengdu Road in the north of Wudadao also attract a large number of potential users, and they have moderate visual sensitivity due to the dense POI facilities. There is still ample room to improve the visual status of the landscape located in the construction control area, which is the main area of district planning and management. The area of low visual sensitivity

accounts for about 28.7% of the total area, most of which is located in the southwest of Wudadao and near Hubei Road. The public pays little attention to it, and tourism services and management facilities can be developed in these areas. Very low visual sensitivity areas account for about 11.5% of the total area, which is mainly located in the construction control area of Wudadao and is largely ignored. These are potential development areas for the district landscape. By comparing the research results with the actual situation in the study area, it is found that the two have a high consistency, confirming the feasibility and reliability of the method described in this paper.

Although the existing documents for protection planning of historic districts in China do not include the assessment of the landscape visual sensitivity, this situation is expected to be improved in the near future. In recent years, the government and the public have been paying more and more attention to the quality of the urban environment. "Urban renewal" was included in the Prime Minister's government work report for the first time in 2021, proposing to accelerate the construction of livable, green, resilient, smart, and cultural cities. Historic districts, as an important carrier of the historical context of cities, have also received full attention from the government authorities. At this stage, the protection and renewal of these districts are supported with favorable policies, and the main tasks faced by departments of management, planning and designing are to carry out research and implement various assessment criteria. Under such a background, the research results presented in this paper can provide an objective basis and easy-to-implement assessment methods for improving policies for the historic districts protection and renewal, satisfying such realistic needs, and they are easy to be accepted and rolled out by the environment management and planning departments. In addition, the development of technology has made it possible for large-scale data collection and analysis. Scholars in related fields at home and abroad have conducted many explorations and attempts on the collection and analysis of open-source data and how they are used for their own research subjects. How to use the available multi-source data for the study of the landscape visual sensitivity of historical districts is an important topic worthy of further research in the future. The research methods and results presented in this paper can provide reference for such attempts.

The study has three main limitations. First, the time dimension is not added in evaluating the landscape visual sensitivity. In future research, the influence of seasonal changes and other time factors on the landscape visual sensitivity need further consideration. For instance, in a time span of 1 year or even 10 years, investigating the changes in the visual sensitivity of historic districts has important theoretical and practical significance. Second, the assessment criteria still need to be supplemented and improved. For example, future assessment criteria can add more open-source website data such as a Baidu Heatmap to objectively and quantitatively measure the number of potential users in the study area. In addition, this study only analyzes the impact of the kernel density of POI data on the landscape visual sensitivity, and POI data can be further classified in the future study to analyze how POI diversity impacts on the visual sensitivity of landscape. Third, this study limits the scope within the visual field, while the effects of hearing, smelling, and other senses on the landscape sensitivity are not considered. In the future, multi-sensory research on landscape sensitivity can become a new point for research in this field.

5. Conclusions

Nowadays, the concept of historical protection is deeply rooted in people's hearts, but there is still much room for discussion in terms of specific means and methods. Worrying about the negative impact of renewal and construction in the historic district and adopting a strategy of "absolute protection" cannot preclude the further decline of the historic district. On the contrary, in line with the principle of giving priority to the historical context, organic renewal is a wise move to enhance the vitality of the district, to coordinate the spirit of the district, and to improve the sustainable development of the material environment. The key to solving such a contradiction is to manage the historical landscape

with classification through a visual sensitivity assessment. In this study, the MCE method based on GIS technology is adopted, and eight map-based criteria (relative slope, relative distance, visual probability, Kernel Density of historic buildings, Kernel Density of POI, valuable landscape, bus stations, and visual hotspots) were used to evaluate the visual sensitivity of historic districts from three aspects: visibility, the number of potential users, and remarkableness. This method provides the possibility of identifying the visual sensitivity of historical districts and provides a more objective and scientific decision-making basis for multi-purpose planning and environmental management. Through the quantitative visual sensitivity assessment of district-scale landscape, the distribution of different levels of visual sensitivity of historic districts was obtained. The research results can help planners and environmental managers of the historic district determine which visual landscapes should be protected and take corresponding protection and renewal strategies for different levels of sensitive areas, so as to avoid the adverse visual impact of the future construction behavior of the district on the high visual sensitivity areas. The landscape of such an area should be paid close attention to and managed carefully.

The data relied on by this method is featured by open source, stability, and easy access, and neither expert evaluation nor high demand for extensive fieldwork are needed. For that reason, this method is easy to apply and can be repeated in the evaluation work, and it can be readily integrated into the planning and management system of historical districts. In addition, based on previous research, this study has made certain contributions in three aspects: the type, scale, and assessment criteria of the study area. Keeping in mind the problems of the previous research, including the single type and single scale of study areas and insufficient use of big data, this study used traditional data and multi-source open data to prove that it is feasible and reliable to apply the common assessment criteria, after being optimized, to evaluate small-scale historic districts for visibility sensitivity. However, the use of emerging open data in this research is still in an initial, exploratory stage. The continuous development of artificial intelligence technology has laid a foundation for the acquisition and analysis of large quantities of open data. How urban big data can be used to serve the assessment of landscape visual sensitivity can also be regarded as a subject of continuous research and exploration in the future.

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