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Study on the utilization of rainwater resources in urban green space landscape planning based on GIS technology

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ABSTRACT

The aim is to solve the blindness of urban landscape planning and the imbalance of urban ecology and promote the sustainable development of the city. Firstly, it analyzes and summarizes regional culture and urban area. Combined with geographic information system technology, the urban green space planning is analyzed. Using digital elevation model algorithm, the method and strategy of urban landscape planning and design based on regional cultural background are obtained. The precipitation in the study area ranges from 485 to 671 mm, and the precipitation from June to August accounts for 66.4% of the annual precipitation. The annual available rainfall amount in the study area is 5.1268 million m^3, and the potential of rainwater resources is huge. From May to October, the total water requirement of green space plants in the study area was 6.3971 million m^3, and the rainwater collected during the same period was 4.5617 million m^3, meeting 71.31% of the total water requirement of plants. The digital elevation model of the study area was established to determine that the green space with a slope between 3° and 15° was through green space, and the green space with a slope below 3° was catchment green space. The distribution map of water-saving green space in the study area was determined. The area of water-saving green space that can be constructed is 1,664.19 hm^2, accounting for 37.10% of the total area of the study area. Taking water-saving green space as the main part, combining the theoretical knowledge of water conservancy science and geographic information science, the water-saving green space system that can utilize urban rainwater resources is optimized, and the long-term green land rate reaches 43%. The test results show that the project cost increases by 2,000 yuan for every 50 m increase in elevation. The gradient of urban green space is mostly gentle, that is, the gradient is 3% ~ 10%. Combining the theoretical knowledge of water conservancy science and geographic information science, the water-saving green space system which can utilize urban rainwater resources is optimized, so that the long-term green land rate can reach 43%.

Keywords: Geographic information system; Urban planning; Landscape planning; Digital elevation model

1. Introduction

Urban green space landscape planning is to solve the problem of reasonable use scope planning of the urban land and the landscape green space. The purpose is to create a comfortable, healthy, safe and green tourism living space for people and create a sustainable green ecosystem. From the 1980s to the 1990s, the planning ideas and contents of green landscape planning scenic areas had been further studied, and the planning contents and methods had gradually matured. In foreign countries, for the landscape design of scenic spots, European and American countries focus more on protecting regional natural ecology, combing the laws of natural evolution [1], and emphasizing the sustainable development of urban construction and natural ecology. The United States and Canada divide the land management and set up national parks. They realize that natural resources are also crucial resources of urban regional culture, which should not be used only for excessive economic development [2]. Britain emphasizes the sustainable development between rural and urban areas and the design of the traditional regional cultural landscapes. In 1978, the contemporary landscape architect Simonds [3] comprehensively discussed a coordination method in Earthscape: A Manual of Environmental Planning and Design, which is about the construction and development and environmental factors such as land, noise, water, landscape and noise. Forman (1995), an American Landscape Ecologist, proposed an innovative spatial landscape planning model based on eco physical space.

The water consumption of urban green space in China is huge, which leads to the aggravation of the consumption of fresh water resources. Therefore, it is necessary to carry out research on urban green space water saving [4]. The construction of water-saving urban green space has been carried out in many countries. Nordic countries have taken the lead in building 100,000 rainwater recycling facilities. Beijing, Shanghai, Dalian, Xi'an and other cities have also launched rainwater utilization practices to solve water shortage [5]. Taking Weihai City as the practical object, feasible measures for sustainable development of rainwater utilization are put forward. Liu established the digital terrain model (DTM) in Zhaoshan area and calculated the amount of rainwater collected on different underlying surfaces. Zhang et al. calculated the rainwater collected under three annual types in Xiyingzi Town, Inner Mongolia. Song et al. quantified the annual total amount of rainwater collected in the Ring highway of Xi'an. The Penman–Montes model is widely used in the calculation of crop water demand [6]. This formula combines various climatic conditions and the growth coefficients of different crops to determine the actual water demand of crops, and then calculates the real water demand of a crop in the growing season.

In recent years, the continuous acceleration of urban land construction planning leads to some unreasonable urban landscape planning, resulting in the imbalance of the system and the loss of regional cultural characteristics in landscape construction. The essence of urban green space landscape planning and land use is to coordinate public resources and civil resources [7,8]. Reasonable planning of landscape construction and land planning can solve this problem. It is essential to solve these problems and create a city landscape with cultural characteristics. A city's green space landscape planning based on geographic information system (GIS) technology is evaluated. A set of landscape planning and design strategies suitable for the city is designed as a theoretical supplement to guide the landscape planning and design of the city.

2. Urban green space planning

2.1. Historical space planning and ecological resources of Yangxian County

Yangxian County, belonging to Hanzhong City, Shaanxi Province, is located in the southwest of Shaanxi Province. It is in the eastern edge basin of Hanzhong, and adjacent to Foping and Shiquan counties in the East, Bashan and Xixiang counties in the south, Chenggu County in the west, and Qinling Mountain in the north. It is located between 107°11′ and 108°33′ east longitude, and between 33°02′ and 33°43′ north latitude. The latitude span is 0°52′, with the horizontal distance of 92.8 km; the total longitude span is 00°41′, with a horizontal distance of 72.7 km. The total area reaches 3,206 km^2.

2.2. Construction of green space planning model based on GIS

Digital elevation model (DEM) is a core data model used in three-dimensional data for terrain analysis in GIS. Its theoretical basis is a discrete data expression for the terrain and geomorphology on the earth surface. Triangulated Irregular Network (TIN) is an irregular DEM which simulates the approaching terrain surface with some non-overlapping triangles. Generally, DTM is a branch of DEM, which describes the spatial distribution combination of linear and nonlinear combination of various geomorphic factors in elevation such as slope, slope direction and slope change rate. DEM is a 0-level single plane term digital geomorphic model. The three-dimensional geomorphic characteristics such as slope, slope direction and slope change rate can evolve based on DEM plane, forming three-dimensional terrain and geomorphic images close to real.

2.2.1. Slope landscape sensitivity (Sa)

For the observer with a designated location, the larger the landscape part the observer sees or notices, the larger the slope of the angle between the observer's line of sight and the horizontal plane is (0°≤ α ≤90°), and the more sensitive the landscape is [9], that is, the greater the impact of people's construction or transformation activities on the original ecological environment is. The landscape plane area to be seen is set to 1 unit [10] to quantify the slope landscape sensitivity, and the angle (elevation) between the landscape surface with the largest slope and the horizontal plane is set to α. The ratio of the vertical projection area of the landscape surface along the line of sight to the landscape surface area is the Sa, as shown in the equation.

$$\mathrm{Sa} = \sin\cdot\alpha, \left(0° \le \alpha \le 90°\right) \tag{1}$$

Eq. (1) reveals that the α value is actually the slope value of the terrain. Sa is 0 when α value is equal to 0°; when it is equal to 90°, the landscape surface is perpendicular to the sight, and the value of Sa is the largest; in the rest, the value of Sa is between 0 and 1. Table 1 is the corresponding table of slope landscape sensitivity level and α value.

2.2.2. Distance landscape sensitivity (Sd)

For different observers, the visual observation ability and the field observation situation affect the viewing effect. It is essential to set a maximum distance *D* that can clearly see the outline, material or structure of the landscape. The *D* value should be determined according to the size of the site and the actual situation of the terrain [11]; the actual distance between the observer and the landscape is d; Sd is quantified by the proportional relationship between D and d, as shown in Eq. (2).

$$\text{Sd} = \begin{cases} 1, & d \leq D \\ D/d, & d > D \end{cases} \tag{2}$$

The D value in the equation can be changed according to the actual situations such as slope terrain characteristics of the park and the field exploration data. The D value is set as 100 m, and Sd is categorized as three grades with different distance zones. Table 2 is the corresponding table of Sd level and observation distance [12].

2.2.3. Visual range probability landscape sensitivity (St)

If the total time of the observer visiting a landscape area is T, while the cumulative time that a scene is seen by the observer in the area is t, the St can be quantified, as shown in Eq. (3).

$$\text{St} = t / T \tag{3}$$

St is 1 when the value of t is infinitely close to T, suggesting that a landscape can always be seen by the observer in a certain area; in other cases, the St is between 0 and 1.

2.2.4. Comprehensive analysis of landscape sensitivity (S)

In real landscape planning and design, the environmental factors in the same area exist together and affect the landscape sensitivity of the planning land. Hence, the comprehensive evaluation of landscape sensitivity is the result of the integration analysis of individual factors, and the functional relationship among them is shown in Eq. (4).

$$S = k1\text{Sa} + k2\text{Sd} + k2S \tag{4}$$

Table 1
Corresponding table of Sa level and α value

Sa level	*A*	*B*	*C*
Sa value	0.5–1	0.25–0.5	<0.25
α value	30°–90°	14.5°–30°	<14.5°

Note: Sa is slope landscape sensitivity; α value represents the slope value of the terrain.

Table 2
Corresponding table of Sd level and observation distance

Sd level	First level	Second level	Third level
Sd value	1	0.5–1	<0.5
d value	0–100 m	0–200 m	<200

Note: Sd is the distance landscape sensitivity; *d* value indicates the actual distance between the observer and the landscape.

The weight value of each factor can be classified and distributed according to their landscape sensitivity, along with the planning objectives and requirements of the park.

2.3. Urban landscape planning and design methods

Moreover, small hills, artificial lakes and rockeries with twists and downs can be designed. In planning and design, the human intervention on the scenic area environment needs to be minimized, natural landscape space and local conditions, such as cultural elements, should be combined, and natural landscape should be integrated with human design ideas. The following are a brief description of the rules for urban landscape design and road design [13].

2.3.1. Principles of urban landscape planning

- Principles of natural ecology and diversity: it is essential to follow the law of natural development, imitate the structure of ecological groups, and take greening, plants and art as the main body. Moreover, the focus should be put on the ecological restoration and construction of urban parks, and continuous improvement of the coverage rate of greening through vegetation planting. Hence, the park can give full play to the urban green lung function, natural and interesting park landscape can be produced, and a rich and diverse ecological environment can be built [14].
- Principle of sustainable development: the comprehensive improvement of the environment should be focused on, and the relationship between the current and future long-term development needs to be dealt with. The local culture should be continued, and the overall consideration and comprehensive coordination need to be achieved through the construction of human landscape and space environment, so as to realize the comprehensive development and utilization, and lay a good foundation for the sustainable development of the city.
- Operability principle: the park planning should be in line with the current situation of the base, and the landscape and service facilities should be arranged according to the shape and situation of the mountain, so as to minimize the amount of earthwork and avoid soil erosion; it is essential to maintain the connection of the overall spatial structure of the planning area, and strengthen the organic connection with the urban green space landscape system and urban architecture.

2.4. Analysis of comprehensive factors evaluation of construction

The comprehensive factor evaluation of landscape construction focuses on whether the planning and construction are reasonable or not, mainly from the two indicators of space and environment. Each category is further divided into many first-level indicators and their corresponding second-level factors. For example, the first level factor of the spatial index is the terrain factor, including H items of the second level factor, such as elevation, slope, aspect and so on. Table 3 is the evaluation table of comprehensive evaluation factors of urban landscape construction planning.

The construction area can be divided into three categories according to the evaluation and analysis table. The first category is the area with good geological conditions or the current construction area, where construction will not exert any impact on the ecological environment; the second type is the area with good construction conditions, good ecological environment and limited function types. The third kind of construction area is not suitable for construction. The construction conditions are not good, and it is not suitable for human activities.

2.5. Technical route of green landscape planning and design

Fig. 1 is the design route of green space landscape planning.

2.6. Penman–Montes formula calculates the water requirement of green space plants

The calculation of water requirement of green space plants provides quantitative basis for rainwater utilization. The modified Penman–Montes formula has been widely used in the calculation of crop water requirement. Based on the meteorological data over the years, the revised Penman–Montes formula and the garden coefficient method were used to calculate the water requirement of green space plants in the study area:

$$\mathrm{ET}_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \dfrac{900}{T+273} u_2\left(e_a - e_d\right)}{\Delta + \gamma\left(1+0.34u_2\right)} \quad (5)$$

where ET_0 is the reference crop evapotranspiration in an hour, mm/d; Δ is the slope of the pressure-temperature curve of saturated water, kPa/°C; R_n is the net radiation of canopy surface, MJ/(m d); G is soil heat flux, MJ/(m² d); γ is the hygrometer constant, kPa/°C; u_2 is the wind speed at a height of 2 m, m/s; e_a is saturated vapor pressure, kPa; e_d is the actual vapor pressure, kPa; T is the average temperature, °C. The plant water requirement (ET_0) calculated by The Penman–Montes formula is used as the reference crop eviction, and the actual water requirement (ET) of garden plants is obtained by the garden coefficient method.

$$\mathrm{ET} = ET_0 \cdot K_L \quad (6)$$

where K_L is the crop coefficient, which is different from the planting of a single type of crops. When selecting the garden plant coefficient, the plant species, planting density,

Table 3
Evaluation of comprehensive factors of urban landscape construction planning

Evaluating indicator	Indicator type	First level indicators	Weight	Second level indicators	Weight	Grading standard		
						It is suitable for construction	Construction is possible	It is not suitable for construction
Urban landscape design	Space	Terrain	M1	Elevation	M11	<30 m	30–80 m	>100 m
				Slope	M12	<5%	5%–13%	>13%
				Slope aspect	M13	Face south	Face east-west	Face north
Design and construction	Environment	Geology	M2	Natural disaster	M21	Area without the natural disasters	Area with fewer natural disasters	Area with more natural disasters
				Bearing capacity of foundation	M22	>250 Kpa	180–250 Kpa	<180 Kpa

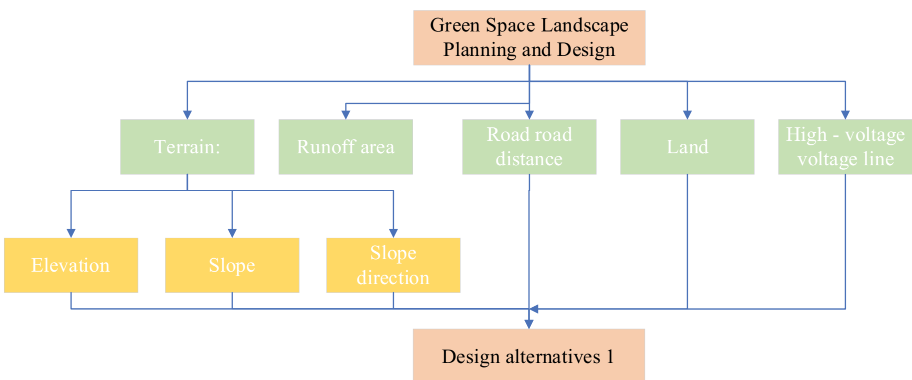

Fig. 1. Green landscape planning and design technology roadmap.

and microclimate factors formed should be considered. The calculation formula of K_L is:

$$K_L = K_S \cdot K_d \cdot K_{mc} \quad (7)$$

where K_S is the garden plant species factor; K_d is the planting density of garden plants, and K_{mc} is the microclimate factor formed by garden plants. The K_S value is related to the coordination type among trees, shrubs and ground cover plants. The value of K_d was affected by the planting density among plants and the spatial canopy width formed by plants. The value of K_{mc} is related to the light, wind speed, humidity and shade of the plant environment. The green space planned in this paper is mainly in the mixed form of trees, shrubs and ground cover plants. The mean value of K_S, K_{mc} and K_d is 0.5, 1.0 and 1.0. The calculated K_L value was 0.5.

3. Measurement results and analysis of urban green space

3.1. Slope measurement results based on GIS

Fig. 2 shows the construction cost of green space with different elevation planning.

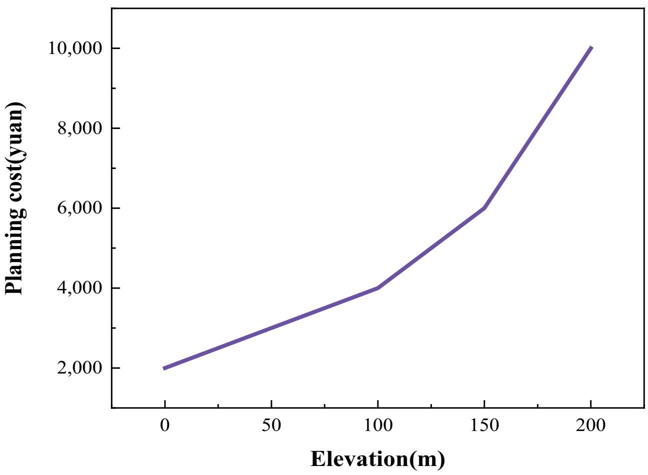

Fig. 2. Cost chart of different elevation planning.

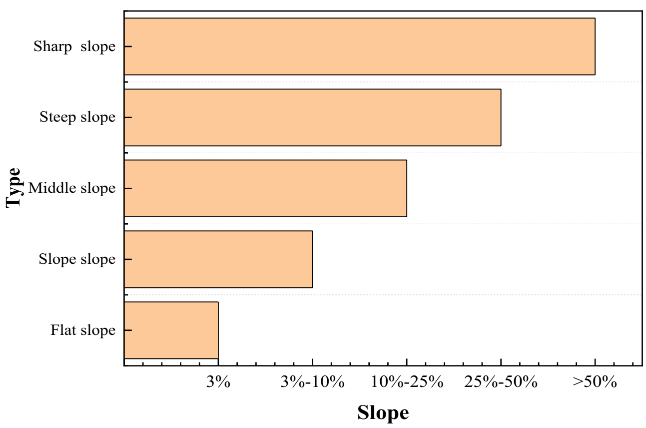

Fig. 3. Slope type diagram.

Fig. 2 shows that the construction cost will increase by 2,000 yuan for every 50 m elevation increase. Usually, the urban landscape green space planning and design will include the natural mountain and water landscape. Fig. 3 displays the specific slope types of the whole city.

Fig. 3 shows that sharp slopes account for the largest proportion. From the perspective of economic analysis, it will increase the difficulty of engineering construction and the probability of natural disasters to carry out construction planning in steep slope areas. From the perspective of environmental protection, the construction planning of artificial landscape green space on steep slopes will also have great destructive power and influence on the original natural environment, such as the local green space vegetation, soil and rock layer, and increase the risk of soil and water loss. To sum up, urban green space planning should be combined with the slope of the local terrain to select and design a suitable green landscape.

3.2. Measurement of green space information dimension based on GIS

After the dimension test of urban green space information based on GIS, the results of Yangxian green space information are displayed by the moving fitting method in the elevation model. Fig. 4 presents the morphology of urban green space.

Fig. 4 suggests that yellow represents the flat zone, green represents the gentle slope area, and blue represents the steep area. It shows that the gentle slope is suitable for urban green space, and the urban slope is generally 3%–10%.

3.3. Model map of landscape design based on GIS

Fig. 5 is a partial view of urban landscape model design.

In Fig. 5, a partial drawing of the landscape design model is provided for design reference. The core area generally has a buffer zone. The two core areas are connected by corridors. The two sides of the corridor are covered by green plants, where fountain design and viewing pavilion can be added. Besides, cultural elements based on urban culture can be involved.

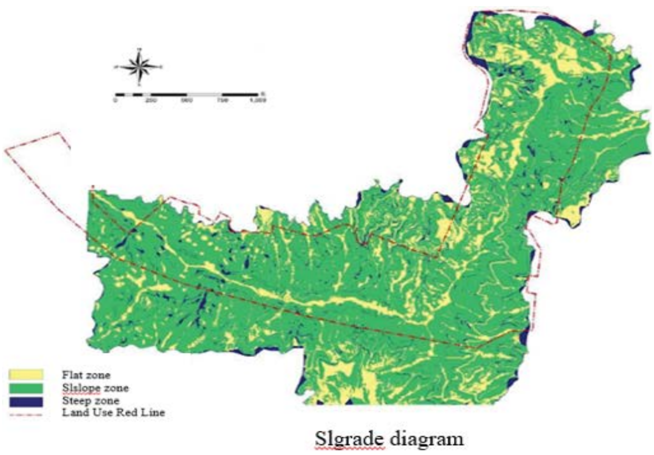

Fig. 4. Urban green space topography.

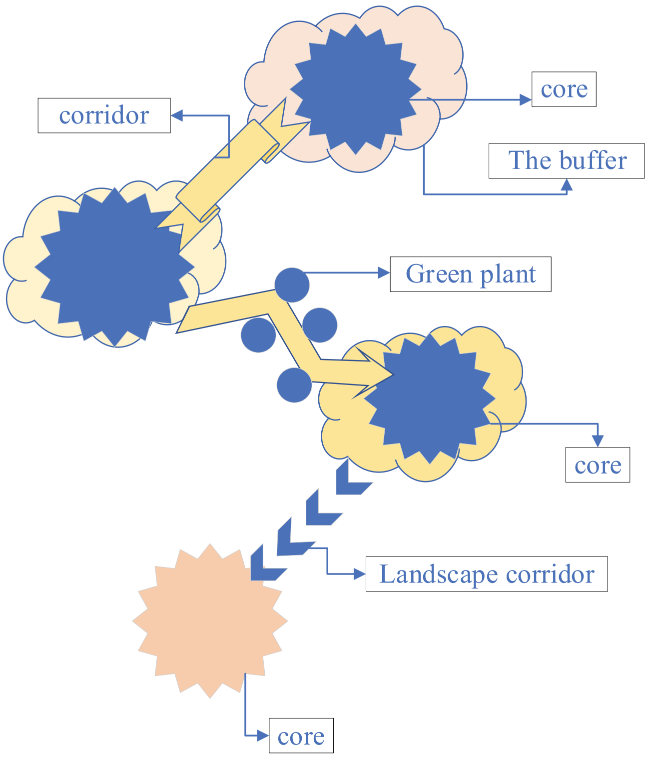

Fig. 5. Part of landscape model design.

3.4. Comparison of green space water requirement and rainwater collected in the study area

Eqs. (5)~(7) are used to calculate the water demand of green space plants in the growing season from May to October. The results show that the total water demand of green space plants in the study area varies greatly. The minimum water demand of plants in October is only 508,200 m^3, and the maximum water demand of plants in June is 1,388,800 m^3. The total water requirement of plants from May to October was 6.3971 million m^3. The amount of rainwater collected in the study area varies greatly from May to October. The maximum amount of rainwater collected in July is 1.4673 million m^3, and the minimum amount of rainwater collected in October is only 2,391 million m^3. The total amount of rainwater collected in the study area from May to October is 4.5617 million m^3, reaching 71.31% of the water requirement of plants.

4. Conclusion

The field survey of urban landscape based on GIS technology has important reference value for urban landscape planning and rainwater water-saving green space. Arc Map grid spatial data analysis algorithm was used to accurately calculate slope, slope aspect and elevation geographical factors, as well as precipitation. Penman-montes formula was used to calculate and quantify the water requirement of green space plants. The calculation results show that the project cost will increase by 2,000 yuan for every 50 m increase in elevation. From the topographic map of urban green space, it can be seen that the slope of urban green space landscape is mostly gentle, that is, the slope is 3%~10%. The research results have important reference value for urban landscape planning, especially for urban landscape projects with complex terrain, and can better reflect the practicability and efficiency of GIS. The green space with a slope of 3°~15° is determined to be permeable green space, and the green space with a slope of less than 3° is catchment green space. The area of water-saving green space can be planned to reach 1,664.19 hm^2, accounting for 37.10% of the total area of the study area. The distribution of water-saving green space in the study area was positioned and the water-saving green space system was planned to realize the ecological function of water-saving green space. However, there are still some deficiencies, such as the lack of project data collection and urban landscape green space data (soil fertility, soil structure and vegetation type distribution map and other basic data) sharing. Various spatial analysis modules, including the calculation of visitor capacity, are rarely used in urban landscape planning. Theoretical research needs to be further improved. The scientific application of GIS technology in green space planning provides technical reference and theoretical basis for the subsequent urban landscape planning and design.

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