RESEARCH ARTICLE

Research on sustainable utilization strategy of rainwater resources based on hydrodynamic models

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With the increasing prominence of extreme climate events and the construction and development of scenic areas, strengthening the management of rainwater resources in scenic areas has become an urgent need to enhance the capability to resist rain-induced flooding disasters and utilize rainwater resources for building safe, ecological, and sustainable scenic areas. In this paper, the Yesanpo scenic area was taken as the research object. Based on topographic and hydrometeorological data, the soil conservation service (SCS) model and ArcGIS spatial analysis tools were used to simulate the inundation areas resulting from an extreme daily rainfall event that 100-year return period within the research region, and comprehensively analyze the inundation areas. Drawing inspiration from the concept of resilience in ecology, this study proposed the construction of rainwater resource management strategies at three levels of ecological resilience, facility resilience, and social resilience. These strategies aimed to facilitate the transformation of stormwater from disaster to resource, thereby enhancing the systemic resilience of the Yesanpo scenic area against floods and water scarcity issues. At the same time, these strategies promoted the construction of resource-saving and environmentally friendly scenic spots, committed to treat rainwater as a valuable resource, and achieved the goal of rainwater recycling, providing a new perspective for promoting the sustainable development of scenic spots.

Keywords: resilience concept; recycling and utilization; sustainable development; rain resource management.

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Introduction

In recent years, there has been an increased frequency of extreme weather events, leading to heightened frequencies and intensities of floods and droughts [1]. This phenomenon has worsened the unequal distribution of water resources between the wet and dry seasons, resulting in various issues related to water safety, aquatic ecosystems, and the water environment [2]. The mountain torrents caused by rainstorms in July 2012 resulted in direct economic losses of more than 7 billion Chinese yuan, 26 deaths, and 20 missing in the Yesanpo scenic area located in Hebei Province, China [3]. The heavy rainfall caused by Typhoon Dujorui on July 29, 2023 led to widespread disaster in the entire region of the Yesanpo scenic area. The affected population reached 73,000, and the area of soil erosion reached 66,646 hectares [4]. Concurrently, research indicated a trend of increasing aridification in Baoding City, Hebei, China with a rise in the occurrence of spring and summer droughts [5]. On the other hand, as scenic areas undergo development and construction, the demand for water in these areas is steadily increasing. Scenic spots, while facing the risks of floods and droughts, are also under pressure to sustain a growing demand for water supply [6]. To alleviate the negative effects of climate change, address the contradiction between frequent flooding in the rainy season and water scarcity in the dry season, and meet the requirements for sustainable water supply in the future, strengthening rainwater resource management in scenic areas becomes a necessary choice. Currently, the management of rainwater in scenic areas relies predominantly on grey infrastructure for rapid drainage, leading to issues such as combined sewer overflows and, to some extent, resulting in the wastage of rainwater resources. In this context, constructing a safe, ecological, and sustainable rainwater resource management strategy is imperative. This strategy aims to enhance the scenic area's capabilities in flood control, drain-age, and rainwater resource utilization, promoting ecological, environmental, and economic benefits.

At present, research on rainwater resource management at the spatial level is mainly concentrated in urban [7] and park areas [8]. The approaches to rainwater resource management primarily involve the construction of green rainwater storage systems through the establishment of green infrastructure [9]. Current research on green rainwater infrastructure predominantly focuses on the classification [10], utility [11], and layout [12] of such facilities. However, there is a lack of comprehensive studies and methods from a systemic perspective covering ecology, environment, resources, and society regarding rainwater resource management in scenic areas.

This research integrates the ecological concept of resilience into rainwater resource management, exploring comprehensive management strategies from a multidimensional systemic perspective. This paper took the Yesanpo scenic area as a case study and employed the Pearson Type III frequency curve to calculate the design rainfall corresponding to the 1% rainfall frequency in the research region. Using the soil conservation service (SCS) hydrological model and ArcGIS spatial analysis tools, the study simulated the rain-induced inundation areas resulting from this design rainfall, compiling relevant data from the inundation zones for comprehensive analysis. Guided by the resilience concept, particularly applied to the rain-induced inundation areas, the rainwater resource management strategies were developed across ecological resilience, facility resilience, and social resilience dimensions. These strategies aimed to promote the reuse of rainwater, enhance the resilience and self-recovery ability of the study area against floods and drought disasters, and accomplish the objective of minimizing resource wastage and promote rainwater recycling.

Materials and methods

Study area and data sources

The study focused on the Yesanpo scenic area, situated in the northwest region of Baoding, Hebei, China (115° 18′ 52" to 115° 30′ 60" E, 39° 34′ 51" to 39° 45′ 43" N). The annual precipitation in this area is 628.8 mm, which is 7.8 mm more than that in the plain area. The rainfall is mainly concentrated from June to September. The monthly precipitation days are 7.2 days, and the monthly precipitation is 69.5 mm, forming a humid and rainy micro-climate. This study obtained the measured daily rainfall data of 32 years (1990 - 2021) in the study area provided by local meteorological bureau, the Digital Elevation Model (DEM) data (specifications: 30 m × 30 m), as well as the Gao Fen 2 (GF-2) remote sensing image on April 16, 2018, comprises a 0.8-meter resolution panchromatic band and 4-meter resolution multispectral bands. Firstly, these images were converted into data with unified geographic coordinate system and projection coordinates system through ArcGIS 10.5 and ENVI 5.3. Secondly, the following operations were performed including orthorectification, image fusion processing, geometric correction, image Mosaic, image clipping, *etc*. Using the boundary vector data of the study area as the reference, the imagery was cropped to obtain the study area image.

Pearson-III type frequency curve

The Pearson III (P-III) type frequency curve is suitable for predicting and analyzing the probability of extreme weather events such as

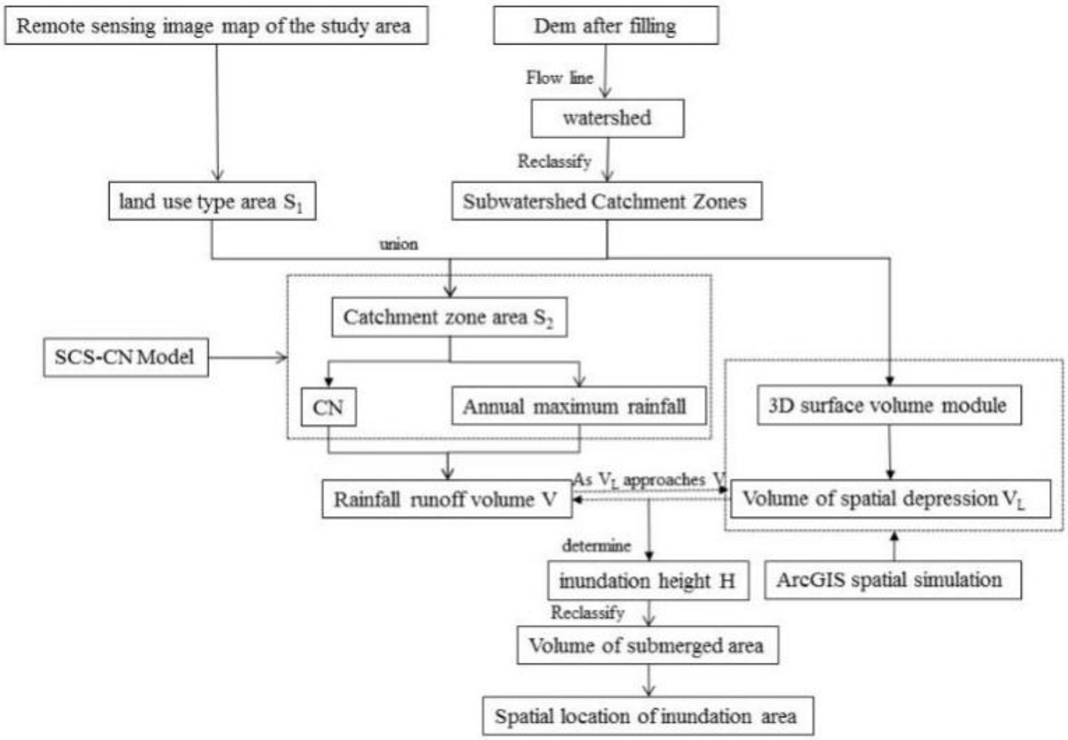

Figure 1. Process for simulation inundation area.

annual, seasonal, and monthly precipitation, as well as maximum precipitation, maximum wind speed, and maximum wind speed at various time periods [13]. The probability density function of the Pearson type III frequency curve is as follows:

$$f(x) = \frac{\beta^{\alpha}}{\Gamma(\alpha)}(x-a_0)^{\alpha^{-1}}e^{-\beta(x-a_0)} \quad (1)$$

This equation includes the gamma function $\Gamma(\alpha)$, where α is the shape parameter of the frequency density function, β is the scale parameter, and a_0 is the location parameter.

Soil conservation service (SCS) model

The Soil conservation service (SCS) model can objectively reflect the impact of different terrain conditions and land types on runoff and is widely used for rainfall and flood simulation [14]. And the computational formula for this model was as follows:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad P \geq 0.2S$$

$$Q = 0 \qquad P < 0.2S \quad (2)$$

$$S=\frac{25400}{CN}-254 \quad (3)$$

Q represented the direct runoff (mm). P was the total rainfall (mm). S was the potential maximum infiltration [15].

Trial value method

The trial value method was used to simulate the flood inundation in the study area. Firstly, the remote sensing images identified were used to obtain the current land use map. The area of each land type was S_1. Through ArcGIS, the data of DEM after filling the depression was obtained, with which the flow direction and the flow accumulation could be acquired. Through raster calculator, streamline, river network, and the watershed were obtained. The watershed was reclassified and segmented into 12 subbasins based on the given direction to obtain the catchment. By combining S_1 with the catchment of the 12 sub-watersheds, the catchment area

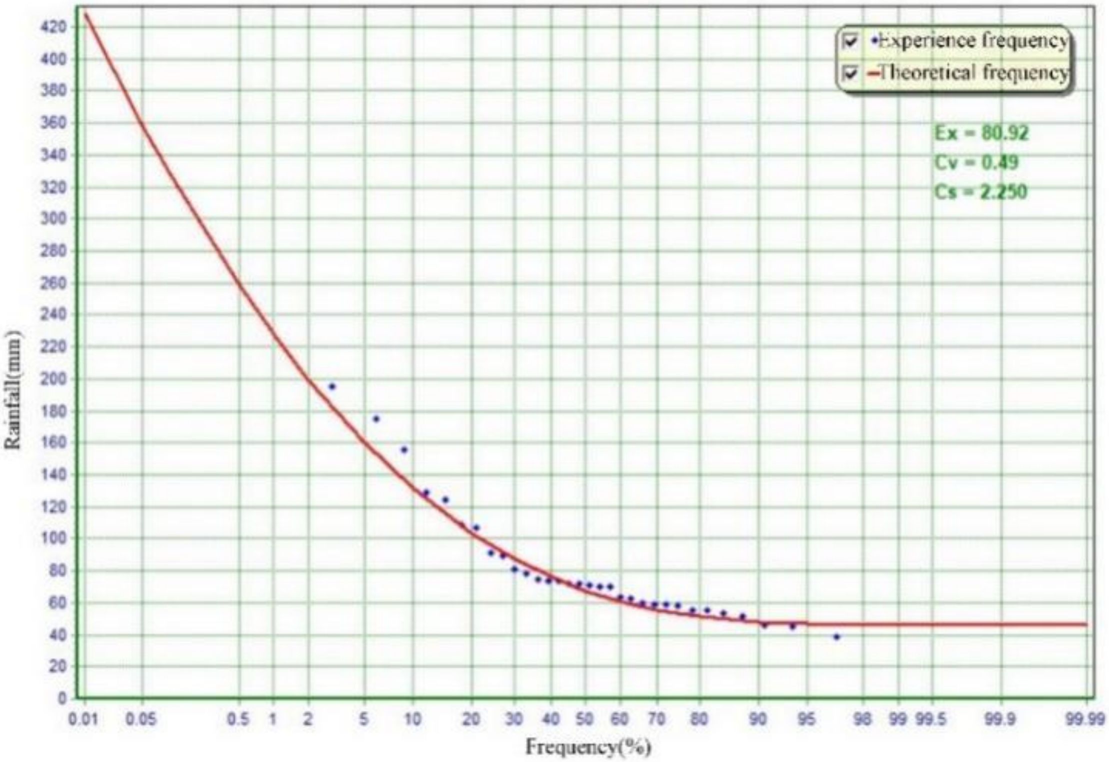

Figure 2. Theoretical Pearson-III Frequency Curve for Maximum Daily Rainfall.

(S_2) was determined. The SCS model was used to calculate the direct runoff (Q) through the maximum daily rainfall, and S_2 was multiplied by Q to obtain the runoff volume (V). The 3D surface volume module in ArcGIS was used to simulate the inundation of DEM, and H_1, H_2, H_3, ... H were obtained from the trial value of submergence height. Thus, the corresponding submerged volume V_L was acquired. When V_L was infinitely close to V, H was the submergence depth. The DEM was reclassified with H as the reclassification standard to obtain the spatial location of the submerged area. The process was shown schematically in Figure 1.

Results and discussion

Design rainfall at 1% rainfall frequency

Generally, the occurrence of rainfall-induced inundation is associated with the maximum rainfall under certain parameters within a year such as the cumulative n-day maximum rainfall, the maximum single-event rainfall, the longest continuous rainfall, and so on [16]. In order to determine the probability of stormwater risk, it is necessary to consider not only the regional geological conditions but also the frequency of rainfall events. The frequency of extreme rainfall can be expressed in terms of return periods, which represent the average time interval for a variable equal to or exceeding a certain value to recur within a long-term period, usually measured in years [17]. Moreover, according to the Standard for Design of Outdoor Wastewater Engineering (GB50014-2021), the design return period for site drainage was set to 100 years. Therefore, based on the 100-year return period for waterlogging in the Yesanpo scenic area, this research simulated the stormwater inundation risk zone of the study area with a rainfall frequency of 1%, which served as the basis for the stormwater risk management. By Pearson-III type theoretical frequency curve, this research obtained the daily maximum design rainfall (Figure 2). The certainty coefficient of the

Table 1. Curve numbers assigned with various land-use types and soil texture of the Yesanpo scenic area.

Land-use type	Soil texture			
	A	B	C	D
Transportation land	98	98	98	98
Construction land	77	85	90	92
Grassland	39	61	74	80
Forest land	25	55	70	77
Farmland	67	78	85	89
Unused land	77	86	91	94
Water	100	100	100	100

Table 2. Runoff statistics for 100-year return period.

Basin	Total area of various land-use types (S_2) (m^2)	Runoff Q (mm)	Runoff volume V (m^3)
1	14857303.800	110.58	1,642,866.40
2	19457235.950	107.44	2,090,580.04
3	19862183.840	104.32	2,071,952.45
4	19673591.520	107.44	2,113,826.33
5	22795920.050	107.44	2,449,304.49
6	7181545.415	107.44	771,620.16
7	17835270.000	101.19	1,804,780.28
8	28310749.100	104.32	2,953,276.76
9	16734457.800	104.32	1,745,679.18
10	22848675.300	101.19	2,312,095.00
11	13878354.790	98.07	1,361,064.56
12	13903935.840	98.07	1,363,573.32
Total	217339223.400	1,251.82	22,680,618.97

theoretical frequency curve was 0.9642, which represented a good fitting effect. Based on this, the design rainfall at 1% frequency for the Yesanpo scenic area was determined to be 228.8 mm.

Runoff forecasting utilizing the SCS model

The curve number (CN) value reflected the runoff production capacity of the SCS model. Determining the CN value requires integration with raster data depicting land use distribution and soil type distribution. Generally, the greater the CN value, the more runoff transformed by rainfall. The CN value in this study was based on the National Engineering Handbook Hydrology Chapters [18]. According to the different land use types in the study area, considering the climatic and environmental factors of the research region, and referring to the research results of similar adjacent areas, this study obtained the CN value as listed in Table 1. According to the soil test of the study area, the brown soil in this area is widely distributed and belongs to class B. Therefore, the CN value corresponding to class B was selected in this study. To derive the watershed distribution in the study area, it was reclassified into 12 sub-basins. Using the SCS model, this study computed the runoff and direct runoff for the 12 sub-watersheds based on the daily maximum design rainfall corresponding to the 1% rainfall frequency in the study area (Table 2).

Spatial positioning and feature analysis of submerged areas

The 3D analysis tool of ArcGIS was used to test the height of DEM after filling the depression. When the water volume resulting from the test

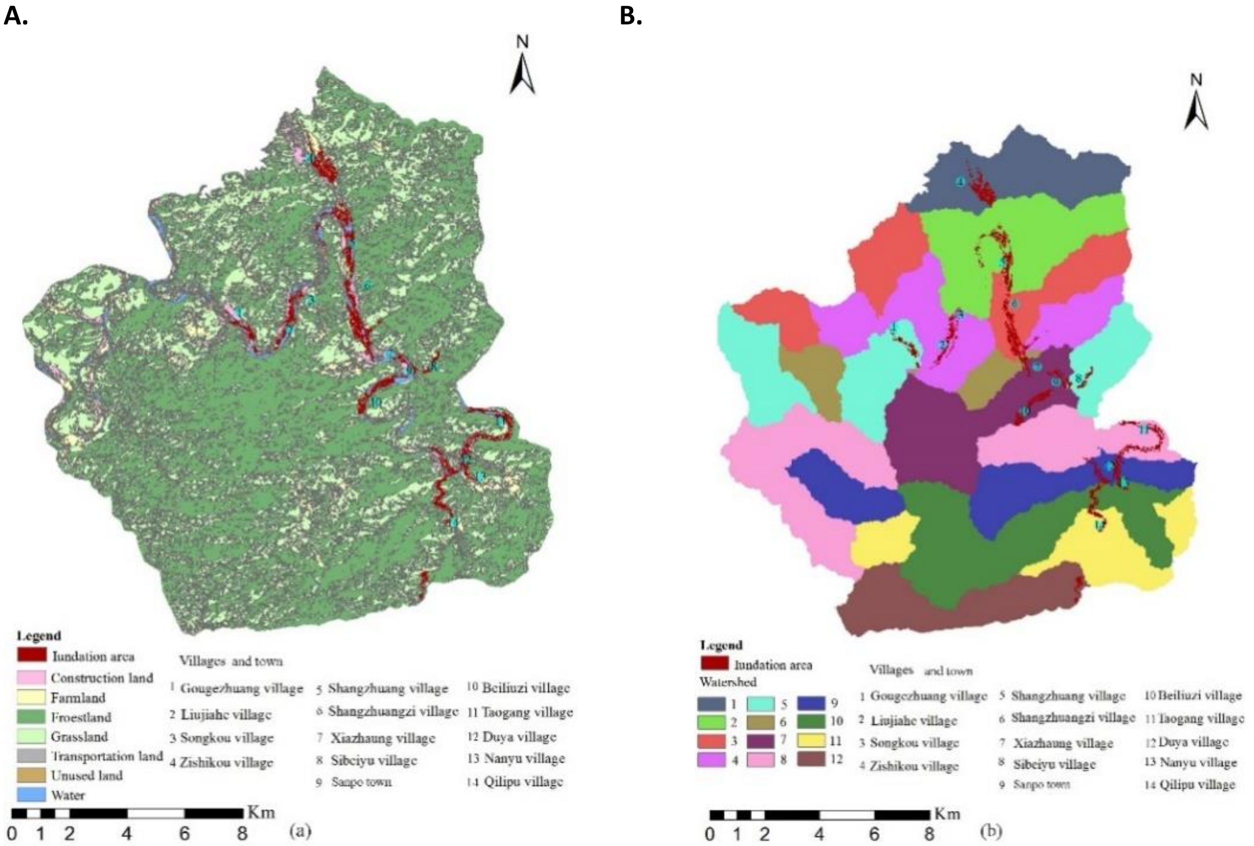

Figure 3. Inundation area’s spatial distribution map (**A**) and distribution map of the inundation area by watershed (**B**).

Table 3. Statistical table of 100-year return period flooded areas.

Watershed	Inundation area (m^2)	Runoff Q (mm)	Runoff volume V (m^3)
1	434,915.990	163.90	71,281.26
2	583,659.070	148.24	86,520.89
3	464,644.210	2.90	1,345.82
4	413,480.200	154.51	63,885.94
5	310,703.670	139.32	43,288.76
6	84,551.840	157.64	13,328.72
7	540,601.440	151.37	81,833.09
8	414,983.150	141.96	58,912.54
9	306,231.310	160.77	49,232.59
10	228,686.580	141.96	32,465.19
11	112,529.145	132.54	14,915.09
12	96,228.770	123.12	11,848.01
Total	3,991,215.370	1,618.23	528,857.90

value's height approached infinitesimally close to the total runoff produced by the 12 sub-basins, the spatial location of the submerged area in the study area was obtained (Figure 3). The total runoff in the flooded area was calculated as 528,857.90 m³ (Table 3). Upon this foundation, spatial analysis tools were employed to further calculate the submerged areas of different land

Table 4. Statistics on the inundation area of different land types with 100-year return period.

Watershed	Water body (m^2)	Grassland (m^2)	Construction land (m^2)	Farmland (m^2)	Forestland (m^2)	Transportation land (m^2)	Unused land (m^2)
1	739.46	31,692.92	69,628.07	231,259.62	18,201.76	35,256.37	48,137.81
2	22,711.33	164,002.73	109,783.66	158,464.27	64,121.88	32,320.26	32,254.93
3	5,636.13	106,985.84	122,580.27	122,524.20	50,137.97	13,186.62	43,593.18
4	17,029.70	93,305.48	118,811.19	41,167.96	56,222.14	16,991.38	69,952.35
5	17,911.78	61,210.56	83,561.06	36,978.69	79,972.27	8,088.56	22,980.74
6	2,699.21	21,905.65	36,608.64	11,128.31	6,353.25	3,666.23	2,190.56
7	20,861.34	116,454.45	88,521.06	104,616.96	82,220.08	19,172.85	108,754.69
8	19,387.66	176,521.81	58,220.91	66,427.81	40,453.19	19,893.77	34,077.99
9	18,688.55	64,231.26	87,884.66	58,449.93	23,060.40	23,811.07	30,105.45
10	2,889.73	56,988.73	43,055.82	56,143.46	43,807.26	76.38	25,725.21
11	0.00	43,657.43	15,788.10	9,883.32	23,584.27	4,536.52	15,079.50
12	114.57	17,969.43	20,943.61	1,692.66	47,065.72	2,458.33	5,984.46
Total	128,669.47	954,926.28	855,387.05	898,737.20	535,200.17	179,458.34	438,836.86

types (Table 4). Utilizing DEM data and employing the 3D surface volume module within ArcGIS, stormwater simulations were conducted to spatially locate inundated areas within the study region, specifically the flood zones generated by the once-in-a-century maximum designed rainfall event in the Yesanpo scenic area (Figure 3). The inundated areas predominantly exhibited clustered point and strip-like distributions, primarily concentrated on both sides of the Juma River basin. Based on the statistics of the inundated area (Table 3), the total inundated area was 3,991,215.37 m^2. As indicated in Table 4, the land types most severely affected by flooding were grassland, farmland, and construction land with inundated areas of 954,926.28 m^2, 898,737.20 m^2, and 855,387.05 m^2, respectively. Figure 3(B) illustrated that the inundated areas were primarily concentrated in basins 1, 2, 3, and 7, while Figure 3(A) showed that grassland inundation was concentrated in the southeast of Gugezhuang village, the northwest of Liu Jiahe village, and the southwest of Shangzhuangzi village. Farmland inundation was mainly distributed near Zishikou, Shangzhuangzi, Hedong, Pingyu, Gugezhuang, and Nanyu villages. Construction land was primarily located in villages within the scenic area including Zishikou village, the sides of Shangzhuangzi village, Sanpo town, Beiliuzi village, Taogang village, Duyu village on both sides, Nanyu village, and scattered residential areas. Additionally, Zishikou village, Shangzhuangzi village, and Sanpo town were key tourist service villages, providing catering, accommodation, and shopping services for visitors. The aforementioned regions should be considered as key construction areas in rainwater resource management.

Sustainable utilization strategies for rainwater resources

1. Ecological resilience level

(1) Conserving and restoring natural ecological systems

Natural ecosystems play crucial roles in water conservation, soil retention, and maintaining ecological balance. According to the interpretation of GF-2 satellite imagery data in the study area, the forest area covers 127,688,000 m^2, accounting for approximately 55% of the total study area. The vegetation primarily consists of temperate species including a diverse array of deciduous and evergreen trees and shrubs. Grassland occupies 80,516,400 m^2, constituting about 35% of the total study area and is dominated by the North China herbaceous plant community, serving both for scenic beauty and landscaping purposes. The water area covers 2,702,480 m^2, approximately 1.2% of the total study area, mainly representing the Juma River system and its associated tributaries. Enhancing ecological resilience involves the protection and restoration of natural systems such as forests,

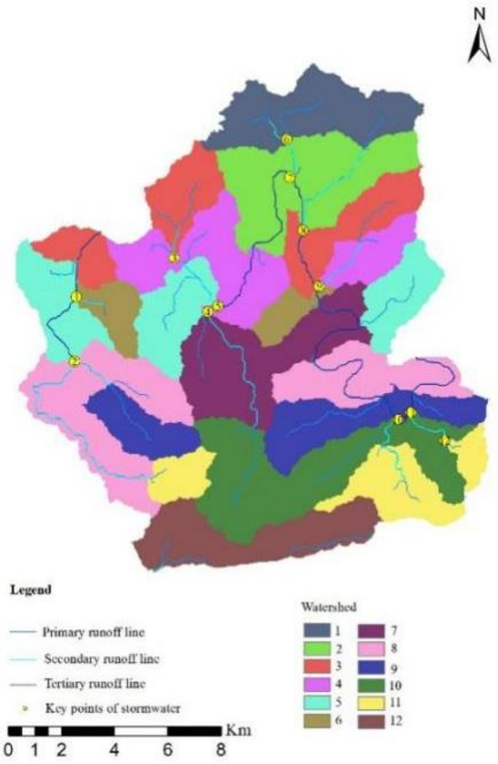

Figure 4. Distribution map of natural runoff corridor and rainwater flood strategy points.

grasslands, wetlands, rivers, and riparian zones. Leveraging the natural functions of these ecosystems including slowing runoff velocity and delaying peak flood formation is essential for reducing rain-induced flood risks and enhancing the resilience of the study area to cope with flood disasters. Additionally, these natural systems can serve as areas for rainwater absorption, providing temporary storage of rainwater to be released during periods of drought, alleviating pressure on water resources.

(2) Establishing an ecological barrier comprised of natural runoff corridors and rain-water strategic points

Natural runoff corridors serve as the natural transport pathways for rainwater runoff, playing a crucial role in reducing peak flows, minimizing surface runoff, and mitigating implicit water sources. Using ArcGIS to simulate and analyze the filled DEM, runoff direction and flow were extracted to construct a river network. Based on this, the distribution of natural runoff corridors in the Yesanpo scenic area was obtained (Figure 4). The analysis revealed the existence of three levels of natural runoff corridors within the area. There were 39 primary runoff corridors, totaling 60,570.85 m in length, along with 19 secondary runoff corridors spanning a total length of 38,446.73 m, and 16 tertiary runoff corridors covering a combined length of 34,782.66 m. The intersection points of natural runoff corridors represent critical strategic points in the rainwater control process [19]. These points serve as crucial locations for the aggregation or diversion of rainwater during rainfall events. Leveraging the natural runoff corridors and strategic points in the research area, an ecological barrier was established, which strengthened the connectivity between different levels of corridors and rain-water strategic points, created ecological rainwater regulation spaces, helped alleviate excess runoff from other areas, prevented the convergence of surface runoff that led to compounded peak flows and thereby reduced flood control pressure.

2. Engineering resilience level

(1) Enhancing flood control grey infrastructure primarily focused on drainage

Grey rainwater infrastructure, primarily focused on drainage, plays a crucial role in mitigating the risk of regional rain-induced flooding and ensuring rain-flood safety. To enhance the engineering resilience of grey rainwater infrastructure, comprehensive planning of drainage systems is essential, which involves a holistic consideration of factors such as regional topography, precipitation patterns, soil conditions, and the practical requirements for the design of drainage systems. An assessment of existing drainage equipment and facilities should be conducted followed by necessary upgrades and optimizations to ensure their normal and efficient operation. The improvement of the drainage pipe network, encompassing main pipelines, branch pipelines, and drainage outlets, is imperative for achieving comprehensive coverage of the entire region. Simultaneously, regular cleaning and maintenance of the drainage pipe network are essential to ensure its optimal functioning. Additionally, reinforcing flood control embankment systems within flood-prone areas due to rain-induced flooding is recommended, which can be achieved through a targeted and segmented construction strategy. Strengthening flood control in villages on both sides of major river basins, creating ample flood discharge areas, and enhancing the capacity to cope with torrential rain-induced flooding disasters are essential measures. These efforts aim to minimize the damage caused by flooding to the greatest extent possible.

(2) Introducing green rainwater infrastructure primarily focused on storage and purification

Farmland plays a crucial role in agricultural economic production. Flooding disasters result in severe economic losses to agricultural production. As indicated in Figure 3, the prime areas affected were arable lands proximal to Zishikou, Shangzhuangzi, Hedong, Pingyu, Gougezhuang, and Nanyu villages, which fell within rain-induced flood-prone zones. These areas faced substantial rain-flood pressure during intense rainfall events. Additionally, arable lands necessitate significant water resources for irrigation during the production process with relatively lenient water quality requirements. Appropriately sitting large-scale runoff facilities such as rainwater wetlands and ponds in low-lying areas of arable land can regulate the spatiotemporal distribution of rainwater resources. This, in turn, enhances the ability of arable land to resist flood disasters, conserves irrigation water, reduces water-related costs, and improves economic benefits. Construction lands are primarily concentrated in villages and towns with relatively dense populations and serve the dual purpose of providing residential and daily life services for scenic area residents and offer tourism-related services such as dining, accommodation, shopping, guidance, and information for tourists. The addition of green rainwater facilities facilitates the retention and purification of stormwater, transforming it into usable water resources. This approach mitigates the impact of stormwater on drainage systems, reduces the load on drainage systems, and concurrently diminishes dependence on external water supplies, thereby enhancing the site's resilience in addressing water scarcity issues.

(3) Establishing a grey-green integrated rainwater resource management model

The retrofitting and expansion of grey infrastructure pose certain challenges, both technically and economically [20]. Based on rainfall-induced flooding simulations and comprehensive analyses, it was proposed to complement the existing grey infrastructure with green rainwater infrastructure. This approach aimed to construct a rainwater resource management model that integrated grey and green rainwater infrastructure, facilitating the connectivity and integration of grey and green engineering facilities. Such an integrated system aimed to address combined sewer overflow issues, establish rainwater resource retention systems, and implement rainwater discharge systems for instances exceeding specified limits. The objective was to ensure rain-flood safety on the site while concurrently promoting the direct recovery and utilization of rainwater resources. This integrated approach not only enhanced the scenic area's resilience against flood disasters but also catered to its growing water demands.

3. Societal resilience level

(1) Establishing a collaborative management mechanism with multi-stakeholder participation

Rainwater resource management involves multiple disciplines and fields, including hydrology, ecology, meteorology, soil science, landscape architecture, and others. Establishing a collaborative management mechanism across various sectors is essential, necessitating a clear delineation of responsibilities among the involved parties. Simultaneously, there is a need for continuous refinement of relevant laws, regulations, and policies. Strengthening legal and policy guidance in the process of rainwater resource management ensures a framework with clear legal foundations and strategic directives, fostering a structured and compliant approach.

(2) Establishing an integrated risk management and emergency preparedness mechanism

By utilizing artificial intelligence technologies and tools, intelligent sensors and monitoring devices can be installed in rain-induced flood-prone areas and rainwater facility zones. These devices enable networked system management and facilitate real-time monitoring of information such as rainfall timing, quantity, intensity, and duration. The intelligent sensors also provide real-time data on the operation of rainwater pipelines, drainage outlets, as well as water levels in the river networks within the scenic area. Concurrently, they capture operational parameters of rainwater facilities in the research area, contributing to the establishment of an intelligent rain-flood management data platform. Simultaneously, the system assesses flood risks, formulates emergency evacuation plans, organizes training and drills, and enhances the responsiveness of residents and community organizations in emergency situations.

(3) Establishing a mechanism for learning, application, and feedback

Communities and residents are not only integral participants in rainwater resource management but also the ultimate beneficiaries of such efforts. By conducting educational and awareness campaigns, residents' awareness and knowledge of rainwater resource management can be heightened. Encouraging their involvement in decision-making and implementation processes is crucial. Emphasis should be placed on incorporating feedback from communities and residents into the rainwater resource management process, continually refining the management system. Establishing a community and resident-centric mechanism for learning, application, and feedback in rainwater resource management is imperative. Active participation and collaboration from communities and residents can drive the planning and implementation of rainwater resource management, bolstering the resilience of the management process and promoting sustainable rainwater resource management.

Conclusion

By using the SCS model and ArcGIS spatial analysis tools, the inundation situation of the study region was simulated under a 1% rainfall frequency. Through a thorough analysis of the flooded areas, the strategies for rainwater resource management were proposed from three levels including ecological resilience, facility resilience, and social resilience, starting from the resilience concept in ecology to regulate and store rainwater in the Yesanpo scenic area, enhance the scenic area's flood resistance capabilities, and encourage the utilization of rainwater resources within the scenic zone. With the aid of the P-III frequency curve, the designed rainfall amount corresponding to the 1% rainfall frequency in the study area was computed and determined to be 228.8 mm. The total area of the inundated zones reached 3,991,215 m^2, generating a runoff volume of approximately 528,857.90 m^3. The inundated area exhibited a primarily clustered distribution in the form of points and strips, primarily focused along both banks of the Juma River basin. Among these, grassland, farmland, and construction land were the types of land that experienced more severe inundation. Based on the resilience concept in ecology, strategies for sustainable rainwater resource management were proposed from three dimensions including ecological resilience, facility resilience, and social resilience. In terms of ecological resilience, the strategy included protecting and restoring natural ecosystems, constructing ecological barriers in the form of natural runoff corridors and strategic points for rain and flood control. Regarding facility resilience, the strategy involved enhancing gray flood control infrastructure with a focus on drainage, establishing green rainwater infrastructure primarily for storage and purification, and concurrently implementing a "gray-green" combined rainwater resource management model. On the social resilience part, the strategy included establishing a collaborative management mechanism involving multiple stakeholders, creating a comprehensive risk management and emergency response plan, and implementing a learning-application-feedback mechanism. This framework provided new perspectives and references for rainwater resource management in scenic areas and arid to semi-arid regions. In addition, there might be some deviation between the designed rainfall data reasonably predicted by P-III type frequency curve and the measured rainfall data. In the future, when the measured rainfall data in the Yesanpo scenic area become more complete, further empirical research can be carried out in this area.

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