

Article

Integrating Sponge City Concept and Neural Network into Land Suitability Assessment: Evidence from a Satellite Town of Shenzhen Metropolitan Area

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Abstract: Land suitability assessment is fundamental in space control planning and land development because of its effects on land use and urban layout. Rainstorms and waterlogging have become one of the most common natural disasters in the coastal areas of China. As a result, the concept of an ecological sponge city was incorporated into the construction of cities in the future. Taking Shenzhen–Shantou special cooperation zone (SSCZ), we constructed a storm flooding model based on the SCS flow generation model and GIS to explore the spatial distribution characteristics of the flooding risk in a rainstorm of 100-year lasting 1 h. Combined with population and economic indicators, a radial basis function (RBF) network was utilized to evaluate the environmental risk, the vulnerability of disaster-bearing bodies, and the rain–flood resilience of sponge cities. The self-organizing feature mapping (SOFM) model was used for cluster analysis. Spatial differences were found in the construction suitability of the study area. A suitable construction area (73.59% of the entire area) was located downtown. The construction of the artificial spongy body in the highest vulnerable area (3.25%) needs to be strengthened. The control construction area (3.3%) is located along the banks of the river, with relatively high risk and low resilience of flood control engineering. Ecological construction (19.85%) serves as the sponge body of ecological buffer. The factors of waterlogging, ecology, population, and economy could be integrated comprehensively by applying neural network methods for urban planning and construction.

Keywords: Shenzhen–Shantou special cooperation zone; SCS model; RBF and SOFM; sponge city; suitability planning of construction land



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1. Introduction

Impermeable surface area gradually expands with rapid urbanization. Whenever a flood season occurs, urban waterlogging becomes a severe threat to people and property [1,2]. Urban waterlogging is a typical natural disaster caused by heavy or continuous precipitation, low-lying factors, and poor drainage conditions [3]. In recent years, urban construction in China has resulted in irrational land expansion [4–7]. As a result of attaching more importance to the facilities aboveground rather than belowground, and toward construction rather than planning, an increasingly prominent problem is occurring in the urban water environment [8]. Thus, the sponge city construction (SCC) program was proposed and adopted quickly nationwide [8,9].

Unfortunately, investigations have shown that backward urban planning and inadequate response measures exacerbate urban waterlogging problems, mostly in developing countries [10]. Usually, land suitability evaluation considers land use, ecological sensitivity,

and land carrying capacity as the influencing factors to determine whether the land is suitable for development and the priority areas for future urban construction [11–14]. However, SCC calls for a higher requirement for the sponge city's land suitability evaluation. Attention should be paid to complicated waterlogging problems on the underlying surface. The diversity in ecological, social, economic, and city development conditions should also be considered when evaluating the land suitability of city sponges [13,15,16].

Studies on land suitability evaluation for sponge cities were divided into two categories according to the evaluation objects. One of them was the suitability evaluation of ecological sponges, for example, water and vegetation. Potential urban green space sponges were divided into protective and constructional types, reflecting the future utilization direction of potential urban sponges [17]. It would play a good role in rain and flood regulation to plan and guide urban green space sponge optimization proposed on regional and township scales [13]. The land area was divided into a low-impact development zone, ecological protection zone, and ecological restoration zone from the perspective of ecological sponge [18]. The ecological suitability evaluation method has already been applied in sponge city development, emphasizing the role of green infrastructure, ecological conditions, and spongy elements in flood regulation [16]. However, waterlogging disasters were not adequately evaluated, therefore the suitability of sponge city construction in the context of rain and flood disasters was not determined.

The other was the evaluation of hydrogeological conditions in urban construction areas. In terms of methods, some researchers have used natural geological factors to evaluate geological suitability [19–22]. Many researchers have simulated urban rain and floods using hydrological, hydrodynamic, and GIS-based approaches [8,17,23,24]. The first two models have been primarily applied for a long time in designing and modifying municipal water supply and drainage projects or water conservation projects, such as SWMM, STORM, MOUSE, InfoWorks C, MIKE FLOOD, and HEC-HMS. However, these models are generally professional, computationally complex, and difficult to couple with ecological, social, and economic factors [25]. GIS-based hydrological analysis tools are widely applicable to areas without hydrological data [3,20,26,27]. In summary, the evaluation of urban hydrogeological conditions focused on total runoff control, urban pipe network planning, and design or measures of sponge city construction [20,28–30]. In addition, these studies were mainly applied in the construction technology of engineering geology or hydrogeology, without considering the vulnerability of urban waterlogging based on social and economic aspects [31].

The losses of population and economy are essential criteria for assessment of the disaster risk in rain–flood cities [26,32]. Thus, population and economic vulnerability should be included in the index system of land suitability evaluation for sponge cities. By doing so, we can predict disaster risk at all stages of planning and select the land with a low degree of waterlogging disaster for urban construction and fixed asset investment. Therefore, there is an urgent need to explore a comprehensive evaluation method for the land suitability of sponge city construction, which not only considers the disaster risk with the background of urban waterlogging but also reflects the integrity of ecological, social, economic, and other factors according to local conditions [15,16].

Accordingly, the planning area of the Shenzhou–Shantou special cooperation zone (SSCZ), with its frequent waterlogging problem, was selected as a case study. First, we used the grid as the minimum evaluation unit. We simulated the range and depth of urban rainstorm waterlogging based on the GIS and Soil Conservation Service (SCS) model. Second, we used the radial basis function (RBF) model to represent the three-dimensional characteristics of the sponge city's hazard, vulnerability, and resilience, and then conducted a clustering analysis using a self-organization feature map (SOFM). This method includes diverse regional, ecological, social, and economic aspects in the land suitability evaluation framework while also considering the waterlogging disaster. This paper attempts to apply the neural network to the construction land planning of sponge cities, hoping to provide constructive guidance for planning other sponge cities.

2. Materials and Methods

2.1. Study Area

The Shenzhen–Shantou special cooperation zone (SSCZ, 115.029° E, 22.873° N), the first special cooperation zone in China, is strategically located at the center of the development linkage of eastern Guangdong. Geographically, the central area is flat, with small hills and mountains distributed in the north. The Nanmen River, Chishi River, and its first branch, the Mingre River, meet here. The area has a subtropical monsoon climate with an average annual rainfall of 2237 mm. Floods frequently occur because of abundant rainfall in the summer (June to September). Continuous rainstorms, in which maximum rainfall can be as high as 285 mm within 24 h, have triggered natural disasters such as mountain floods, urban waterlogging, and landslides, which have increased the risk of flooding downstream and threaten the lives of residents.

2.2. Data Source and Processing

The primary geographic data included DEM data with a spatial resolution of 10 m (i.e., converted from topographic maps), soil dataset (from the national ecological environment survey database, China 1:100,000 soil database), and land use data set of 2019 (from Shenzhen Municipal Bureau of Planning and Natural Resources). Soil texture was classified using soil data according to clay (mc, <0.002 mm), powder (msilt, 0.002–0.05 mm), and sand (ms, 0.05–2 mm) percentage content. The land use data were divided into eight types: garden plot, construction land, forest, water, beach, cultivated land, grassland, and bare land. Points of interest (POI) data were extracted from Baidu maps, such as points of enterprises, schools, scenic spots, restaurants, power plants, and telecommunications services.

Demographic data included the heatmap of population and residential area data obtained and extracted from WeChat travel and topographic maps separately. The population data (TXT) were crawled using Python. The sampling time was at 10 a.m. and 10 p.m. each day of the whole week for three months (February, March, and April) in 2019. The observations collected were averaged to reflect the general tendency of overall population distribution and converted into raster data in ArcGIS. Population density is indicated by the kernel density of the point population distribution. The data were projected to UTM coordinate system zone 50 N and then analyzed using ArcGIS 10.5 software.

2.3. Storm Waterlogging Simulation

Rainfall is a direct cause of urban waterlogging. Measured storm data or designed storm models are often used for simulations to study waterlogging caused by urban rainstorms. The formula for rainstorm intensity (i.e., the formula of rainstorm intensity in Shenzhen and calculation chart (2015)) is in the form of (1) and (2).

$$i = \frac{8.701 \times (1 + 0.594 \times \lg P)}{(t + 11.13)^{0.555}} \quad (1)$$

$$q = \frac{1450.239 \times (1 + 0.594 \times \lg P)}{(t + 11.13)^{0.555}} \quad (2)$$

where i (mm/min) or q (L/s/ha) represents the rainstorm intensity, P (year) represents the recurrence period, and T (min) is the duration of rainfall. The Chicago storm profile was adopted in China based on other scholars' explorations [24], with a rain peak coefficient of $r = 0.5$.

The Soil Conservation Service (SCS) model of runoff generation, an empirical hydrological model developed in 1954 by the U.S. Department of Agriculture, Soil Conservation Service (USDA-SCS), was used to calculate surficial runoff [24,33]. This model, which has a simple structure and low data requirements, considers the impact of the underlying surface conditions on runoff. The flow generation formula for the SCS model follows:

$$Q = \begin{cases} \frac{(P-0.2S)^2}{P+0.8S}, & P > 0.2S \\ 0, & P < 0.2S \end{cases} \quad (3)$$

where P (mm) is the actual rainfall, S (mm) is the potential infiltration amount before rainfall, and Q (mm) is the runoff depth, S is related to the dimensionless parameter CN (curve number), reflecting the comprehensive soil type characteristics, vegetation, water content, land use type, and slope of the watershed before rainfall. The formula for the relationship between S and CN is shown in (4).

$$S = \frac{25400}{CN} - 254 \quad (4)$$

The CN value is the most crucial parameter in the SCS model. The differences in soil textures and land use types lead to differences in runoff generation capacities. Therefore, the SCS model divides soil types into A, B, C, and D, corresponding to soil CN values of different infiltration rates (see Tables 1 and 2). The higher the CN value, the greater the capacity of the underlying surface of the basin. The runoff depth of each catchment area was calculated using the SCS model formula.

Table 1. Different soil texture.

Soil Type	Soil Texture	Infiltration Rate (mm/h)
A	Sandy soil, loamy, sandy soil, sandy loam	7.26–11.43
B	Loam, silty loam	3.81–7.26
C	Sandy clay loam	1.27–3.81
D	Clay loam, silty clay, sandy clay, Silty clay, clay	0–1.27

Table 2. CN values corresponding to different land use types and different soils (AMC II).

Coding	Land Use Type	Soil Hydrology Group			
		A	B	C	D
1	Arable land	67	78	85	89
2	Garden	43	65	76	82
3	Woodland	25	55	76	82
4	Grass	34	60	74	80
5	Water	98	98	98	98
6	Tidal flats	32	58	72	79
7	Bare land	72	82	88	90
8	Low-density urban land	60	74	83	87
9	High-density urban land	90	93	94	95

2.4. Evaluation Index System

The core of the suitability evaluation of sponge city construction lies in disaster factor analysis or risk analysis. Risk definitions include risk (i.e., disaster factors), vulnerability (i.e., probability of possible loss), and recovery (i.e., probability of self-repair of the affected body). People usually cannot preserve nature from disaster-causing factors, but can lower disaster risks by reducing vulnerability and improving resilience in urban ecosystems.

The significance of evaluating the suitability of sponge city construction lies in the possibility of choosing a suitable space for construction investment at the early stages of urban development planning, which reflects the foresight of planning and the tendency to maximize advantages and avoid disadvantages. Considering the definition of the three elements of risk, the three criteria of the rule layer, namely risk to environment, the vulnerability of the hazard-bearing body, and rain–flood resilience of sponge city, were considered comprehensively [3,34]. The ten subcriteria of the child rule layer are normalized and mapped in the range of 0–1 to eliminate the influence of dimension. The ruling layer and child rule layer are listed in Table 3.

Table 3. Suitability evaluation index system of sponge city construction.

Target Layer	Rule Layer	Child Rule Layer	Index Attribute
Land stability of sponge city	Risk of environment	Elevation	+
		Slope	–
		Risk of rainstorm	–
	Vulnerability of hazard-bearing body	Spatial characteristic of residential area	+
		Density of service industry	+
		Spatial characteristic of population	+
	Rain–flood resilience of sponge city	Road accessibility	+
		Perfection of infrastructure	+
		Vegetation coverage	+
		Utilization of existing areas	–

2.4.1. Environmental Risk of the Rainstorm

Safety has always been considered the first principle of engineering construction. There should be less environmental risk of rainstorms in sponge cities with higher land suitability, which was evaluated by elevation, slope, and risk of rainstorm waterlogging. (1) Elevation plays an essential role in floods and waterlogging. The higher the elevation, the lower the risk of waterlogging, and vice versa. (2) The slope is also a factor that restricts urban development planning. Steep slopes, for example, are prone to landslides, while gentle, open areas can be used to create temporary public shelters. Calculated using the DEM, the slope value was assigned to 1 if less than 10° and increased successively every 10° until a value above 55 was assigned to 12 because of the low possibility of development. (3) The risk of rainstorms focuses on the spatial location of occurrence, intensity, inundation range, depth, and other factors. From the perspective of the spatial distribution of rainfall, the spatial difference of rainfall could be ignored owing to the small area and location to the south of the mountain range. From the perspective of rainfall duration, although the cumulative rainfall accumulates with the increase in rainfall duration, the periods of inundation and waterlogging disasters caused by rainstorms in different recurring periods are mainly concentrated in the duration of approximately 1 h. In this study, the design rainfall was 321.895 L/(s·ha), the cumulative rainfall was 116.034 mm, and the rain peak was 5.406 mm/min, taking the case of 100-year rainstorm for 1 h as an example. Based on the SCS model, we obtained the flood risk evaluation results for sponge cities under waterlogging conditions.

2.4.2. Vulnerability of Hazard-Bearing Body

The vulnerability of hazard-bearing bodies directly determines the disaster loss under urban waterlogging scenarios, representing the degree of possible damage and recovery capacity of hazard-bearing bodies when exposed to disasters [28]. The spatial location or quantity of disaster-bearing bodies was determined using GIS spatial analysis tools. Population density, economy, buildings, and other potentially exposed elements in sponge cities were evaluated. The higher the distribution density, the higher the vulnerability. (1) Spatial characteristics of residential areas. The planar residential data were extracted according to the topographic map of the SSCZ in 2016. The percentage of residential areas in the neighborhood window was calculated using the focus statistical tool. The spatial distribution of residential areas reflects the spatial position of people living at night. (2) Density of the service industry. For this index, the point density of various tertiary industries or service industries represents the development level of the service industry and reflects the spatial pattern of urban economic development. (3) Spatial characteristics of the population. Although there is a lack of job–housing balance in cities, the spatial characteristics of residential areas can be supplemented by daytime population distribution data.

2.4.3. Rain–Flood Resilience of Sponge City

Stormwater resilience refers to the resilience of a sponge city when it is subjected to rainstorms and waterlogging disasters, including the resilience of infrastructure in flood storage and the resilience of society in dealing with floods. The evaluation was done using four indicators: road accessibility, infrastructure perfection, vegetation coverage, and existing areas. (1) Road accessibility reflects the ability of urban waterlogging disasters to move around quickly. It is represented by the density of traffic networks within kilometers. The higher the road density, the greater the rain and flood resilience of the sponge city. (2) Perfection of infrastructure was characterized by the Euclidean distance from communication, water supply, hospital, and other infrastructure. The closer the distance to the infrastructure, the greater the rain and flood resilience of the sponge city. (3) Vegetation coverage is represented by the normalized vegetation index (NDVI). Vegetation has the function of flood storage, such as urban green spaces, ecological tree pools, green roofs, and sunken green spaces, which are commonly used in sponge city design. The higher the vegetation coverage, the greater the urban rain–flood resilience. (4) Utilization of existing areas was represented by the Euclidean distance from schools, parks, green spaces, temples, and other public shelters. The closer it is to the public refuge, the higher the probability that residents can avoid danger when danger arises, and the greater the rain–flood resilience of the sponge city.

2.5. Model Principle and Applicability of Neural Network

The RBF is a radially symmetric scalar function. The RBF network is widely used in interpolation and classification research. It is a forward network consisting of an input layer, hidden layer, and output layer. The RBF model needs to learn the center of the radial basis function, the variance, and the weight of the output unit. Each neuron in the hidden layer has a receptive field. RBF directly determines the function center through clustering, and the connection weight of the hidden and output layers can be directly calculated. After establishing the spatial mapping between the input vector and hidden layer, the nonlinear relation becomes linear separable. The RBF learning steps are based on previous studies [35–38].

The self-organization feature map (SOFM) is an unsupervised classification that learns only from input data without an external teacher or judgment instruction. The biological basis of SOFM networks is that they learn evolution in a given pattern and extract features or rules from the data. After acquired learning, neurons in the human cerebral cortex self-organize and self-adapt to form an orderly arrangement [39]. If the input patterns are similar, the corresponding excitatory neurons are similar in each region. For example,

different cortex regions are responsible for perception and information processing, such as vision, hearing, language, and movement control.

Similarly, when SOFM networks accept different input modes, they perform competitive learning, and samples close in high-dimensional space are projected onto a low-dimensional space (output layer). The SOFM network has two layers: an input layer and a competition layer. Each grid node in the competition layer is an output node connected to the other nodes adjacent to it and has the same exterior.

The learning process of the SOFM follows: (1) Weight initialization—assign the initial value w_{ij} (0) to each weight vector w_{ij} with different small random numbers. (2) Input the training sample vector X , and let $t = 0$. (3) Collaboration process—select the winning unit i . The winning unit is selected as the minimum Euclidean distance between the input vector x and ownership vector. (4) Collaboration process—adjustment and correct weights (5) to carry out the following study and repeat the previous steps until all the samples are used. Suppose the neighborhood of the winning unit is not defined. In that case, it can be replaced with a neighborhood function around the winning unit.

A neural network is an operational model based on network topology knowledge. Its intelligent adaptive learning ability and highly nonlinear logic operation are widely used in various fields, such as ecology and land use planning. In the land suitability evaluation of sponge cities, the difficulty of traditional grading evaluation methods is in determining a universal standard of grading index. The evaluation methods of the RBF model performed better by setting evaluation indexes to train existing targets and combining multiple subcriteria to determine the criteria level index. The SOFM networks, which map high-dimensional attribute characteristics to the two-dimensional output plane, can extract the internal rules of complex distribution patterns by making similar sample grids close to each other on the output plane of SOFM networks. Compared with the traditional evaluation method, the neural network method can map the multidimensional spatial sample patterns in the output layer to keep the topological structure unchanged. The mapping from the input to the output layer is a simple data compression and a rule discovery.

The raster data with a spatial resolution of 10 m were unified into the exact size of 1839×2329 in ArcGIS 10.6 software. The clustering center and base witnesses of the radial basis function were determined by the RBF learning algorithm adaptively and by the multiple experiment comparison, respectively, with the output of the rule layer ranging from 0 to 100. The values of the three criteria of the rule layer with 4,283,031 grid pairs were used as the input data for the SOFM network. The competition layer network was set as a two-dimensional matrix with nine (3×3) neurons. Both the RBF and SOFM networks were performed using the MATLAB 2019a software.

2.6. Technical Route

The technical route of this study is shown in Figure 1. First, rainstorm waterlogging was simplified to the evolution process of rain–run–accumulation waterlogging. Second, based on high-resolution DEM data, the ArcGIS 10.5 hydrological analysis module extracted hydrological information. Third, the watershed runoff was obtained based on the SCS model and the formula for Shenzhen rainstorm intensity. Then, according to the principle of passive inundation and equal volume method, ArcPy batch processing was used to simulate the range and depth of each watershed. Finally, based on the results of GIS spatial analysis, the RBF network model was used to obtain the 3D evaluation system of risk, vulnerability, and resilience. Then the characteristic clustering was performed using the SOFM network model. Finally, the land suitability zoning and evaluation of the sponge city were completed.

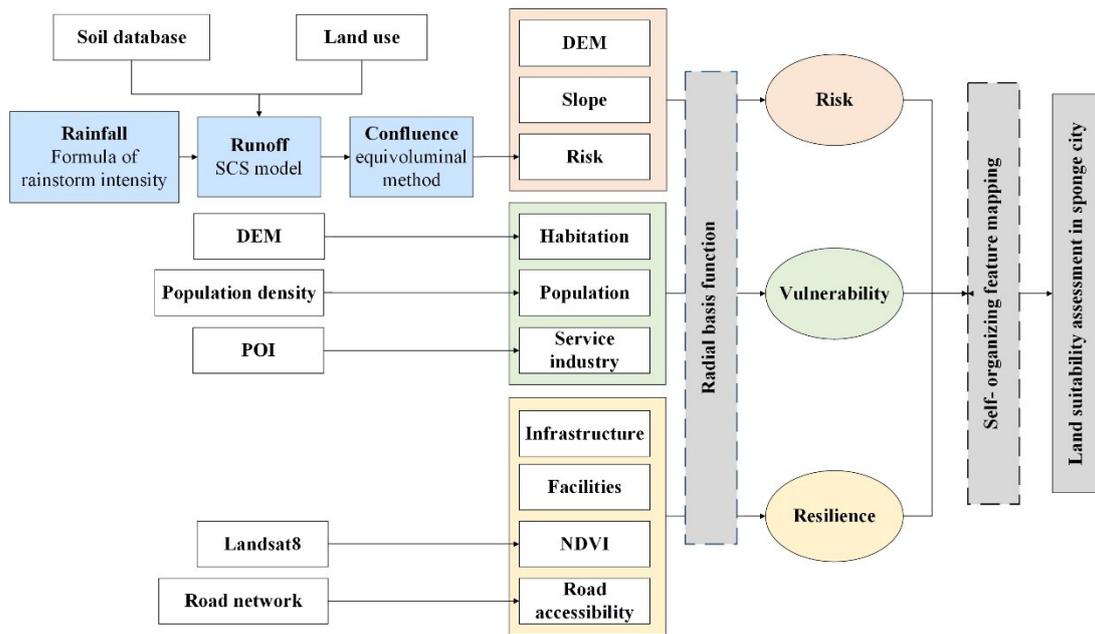


Figure 1. The framework of the land suitability assessment in the sponge city.

3. Results

3.1. Waterlogging Risk and Other Subcriteria

In the case of a 100-year rainstorm of with 1 h duration, the locality of rainstorm waterlogging is evident, and the risk of flooding along the river is the greatest (Figure 2). The risk of inundation is inversely proportional to the distance from the river bank. The other indicators after normalization are shown in Figure 3. The natural, social, and demographic conditions of the urban construction have spatial heterogeneity.

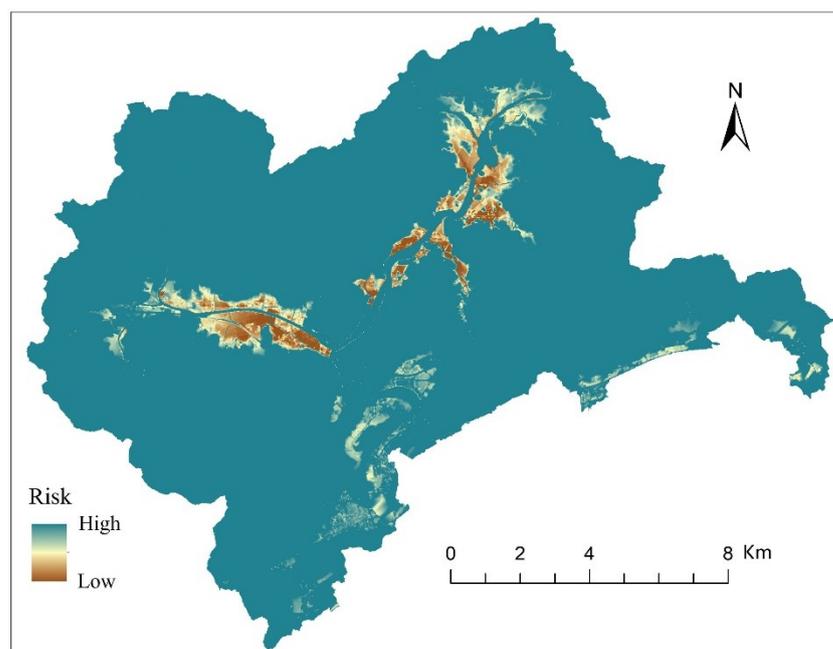


Figure 2. Waterlogging risk of the rainstorm.

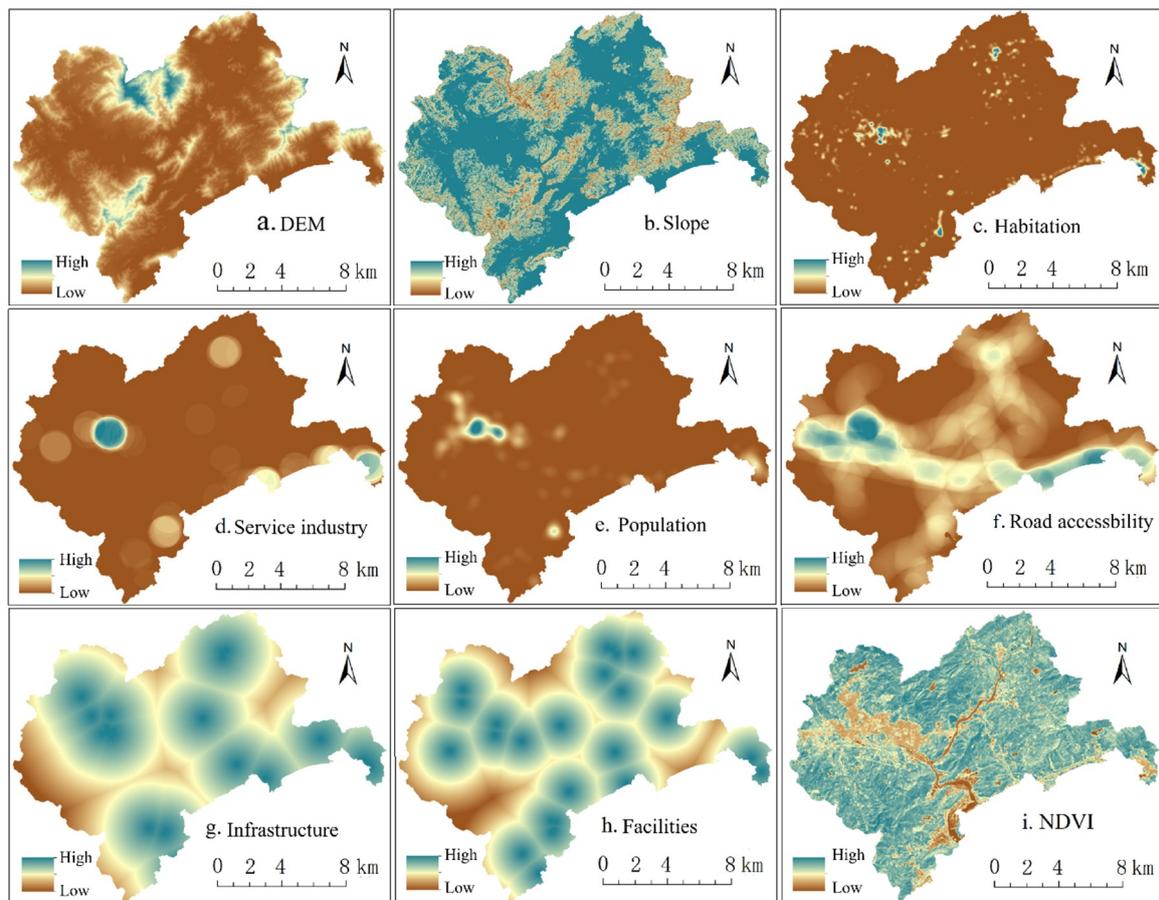


Figure 3. Results of spatial analysis of subcriteria layer.

3.2. Suitability Evaluation of Sponge City Construction

Figure 4a–c shows the following features: (1) There is a higher risk of waterlogging disasters in the northern and southwestern regions due to the higher elevation and lower risk in the region's center where the terrain is gentle and rivers meet. (2) The central area of Ebu town is highly vulnerable because of its dense population and economic development. In addition, catering services, financial services, scientific research and education, companies, entertainment, retail, hotels, and other service industries are concentrated here. (3) The greater the road accessibility, the closer it is to infrastructure, shelters, or ecological sponges, the higher the city's resilience to manage rain–flood hazards. The accessibility of roads shows that the main traffic routes in the region run through the east and west, followed by the north and south. Infrastructure integrity is characterized by the distance from telecommunications, medical services, substations, and communications equipment. The utilization of existing areas is represented by the distance from schools, parks, green spaces, temples, and other public shelters.

3.3. Land Suitability Zoning Results of SOFM Model

The results of land suitability zoning for sponge cities after SOFM network clustering and waterlogging risk correction are shown in Figure 4d. Regions of class I are mainly distributed in the middle reaches of the Nanmen River, including Jiaohu village and Tianliao village on the north bank of the Nanmen River; on the south bank of the Nanmen River, including Xihu village and Yibu village; on the upper reaches of Chishi River, including Xinli village, Xinlian village, Yuandun village, and Xincheng village on the Minger River. Regions of class II are mainly distributed 2 km upstream from the confluence of the Nanmen and Chishi River and on the middle-curved reach of Mingre River. Class

III regions are mainly distributed in the east, west, and north of the area. The regions of class IV are mainly distributed among classes V and VI. Class V regions are located around the city center, including Nanxiang Village, Dongwang Village, Wangyu Village, Yuanxin Village, Yunxin Village, etc., in Xiaomo town and Hongyuan village, Mingxin village, and Mingan village in Houmen Town. Class VI regions are mainly distributed in the center of the town of Ebu and Chishi.

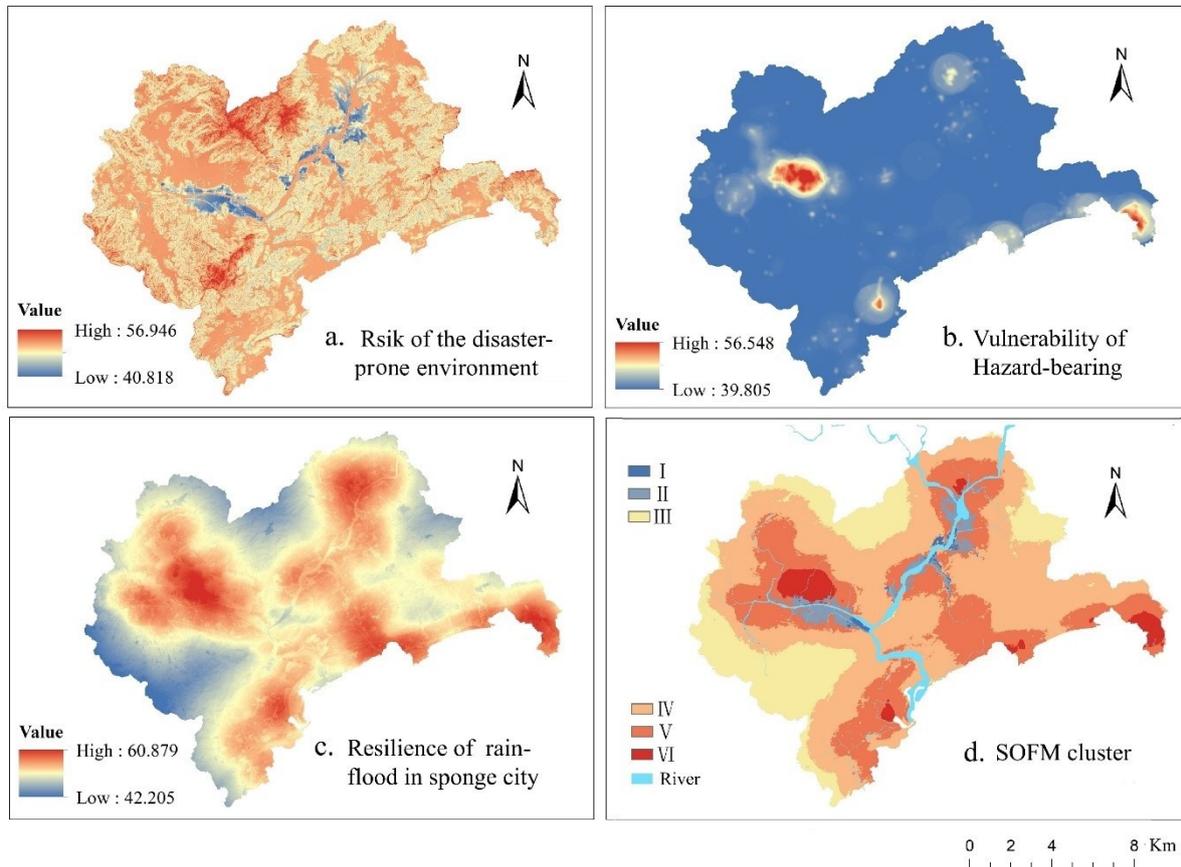


Figure 4. The ruling layer and construction suitability scoring area.

3.4. Land Suitability Characteristics

Table 4 lists the rank orders of the criteria. The dominant factors of class I and II are environmental risk and the rain–flood resilience of the sponge city. Class I has the highest risk and the lowest resilience, accounting for 0.46% of the region. Due to low-lying areas, waterlogging occurs almost whenever there is a rainstorm. Class II is another high-risk and poor resilience category with higher vulnerability than class I in disaster situations due to the more intensive population and economy. Class III performs best in terms of environmental risk and the vulnerability of the hazard body, with an area of 19.85%. Class IV has medium-high vulnerability and risk and has moderate rain–flood resilience, with an area ratio of 47.15%. The performance of the rain–flood resilience of class V is at a medium-high level, and other indexes are ranked in the middle reaches. Class VI has the highest vulnerability and best rain–flood resilience with environmental risk at a medium level.

Table 4. Rank of criteria.

Criteria	Class						
	I	II	III	IV	V	VI	
Risk of environment	6	5	1	2	3	4	
Vulnerability of hazard-bearing body	4	2	6	5	3	1	
Rain–flood resilience of sponge city	6	5	4	3	2	1	
Accounted for	0.46%	2.84%	19.85%	47.15%	26.44%	3.25%	

Land suitability zoning can point out the same space that can avoid the risk of specific natural hazards and be further explored in terms of development status. The corresponding construction measures are proposed for different suitability characteristic zones (Table 5). Regions of classes IV and V are relatively suitable for urban development, regional planning, and site selection. The natural green sponges and water in the area should be fully utilized. More runoff should be intercepted through infiltration, emission reduction, and accumulation use. Regions of class VI, the densely constructed area with the largest population and economy near the river, are generally suitable for sponge city construction. Artificial sponges should be strengthened to improve the adjustment capacity of water storage or reserve a safe distance in case of flooding. Regions of Class I and II are less suitable for sponge city construction, where flood control engineering construction should be strengthened to improve the resilience of sponge cities. Due to the incidences of frequent flooding along the river, it can be developed as flood control land, green parkland, etc., but construction of educational, residential, commercial, industrial, and other such facilities should be avoided. Due to the severe danger, flood prevention safety measures and engineering safeguard measures should be taken. Urban residents' land in dangerous areas can be conceded when necessary. The lowest land suitability of Class III regional construction is not due to the greater risk of flooding but mainly due to incomplete infrastructure, low regional utilization, low economic density, small population, and low road accessibility. According to the concept of adapting to local conditions, the ecology of this area should be prioritized to assume the function of isolation and ecological buffering at the edge of construction land.

Table 5. Suitability construction evaluation and construction measures of sponge city.

Suitability Classification	Class No.	Construction Measures
Relatively suitable for construction	IV, V	Should make full use of the natural ecological sponges in the area. The sponge facilities with strong infiltration capacity, such as sunken green space and biological retention, are considered in particular—select facilities to play the role of infiltration and self-purification of water, including infiltration ponds and wells. Through infiltration, emission reduction, and storage utilization, more runoff will be intercepted.
Generally suitable for construction	VI	Strengthen the construction of artificial sponges. Select the type of LID facilities with small infiltration volume and slow penetration rate, and arrange them in combination with urban gray rainwater facilities, sponge city transmission, and regulation facilities. Construct rainwater storage sponge city facility types, such as rainwater tanks and reservoirs. When necessary, plan the land receding to a certain distance from both sides of the river and set a safe distance for rainwater flooding.
Less suitable for construction	I, II	Combined with urban drainage facilities, alleviate the waterlogging in urban river channels. Strengthen the construction of flood control projects and transmission facilities, such as planting grass ditches along the river for out-of-area transmission of rain floods.
Not suitable for construction	III	Strictly protect the ecological sponge, maintain its sedimentation function and hydrological, ecological processes, and perform isolation and ecological buffering on the edge of the construction land.

4. Discussion

A simplified model of urban rainstorms and waterlogging was built based on the SCS model and GIS. The neural network was used to determine the suitability zoning of the SSCZ, thus providing a scientific basis for the land suitability zoning evaluation of sponge cities. From the perspective of land use, this paper discusses the risk of rainstorms and waterlogging disasters in villages and towns at a small scale and puts forward some suggestions on how suitable the land is for sponge city construction.

Evaluating the land suitability of sponge city construction in the early stage of urban planning is beneficial for improving the risk management awareness of rainstorm waterlogging and inundation hazards on a holistic basis, and for good coordination of urban rainstorm waterlogging prevention. It is a problem of land competition between people and floods to avoid storms and waterlogging in urban spatial layout planning [40]. Generally, if urban spaces are developed in areas with a high risk of waterlogging and low land suitability in sponge cities, it is necessary to determine land use and select appropriate spaces. In terms of land use in high risk areas, construction of public facilities, green spaces in urban parks, or comprehensive services should be promoted, and land for living support services, industry supporting services, and urban transportation should be avoided. The selection of sponge city facilities needs to be tailored to local conditions and detailed engineering survey data [3,41].

The risk of rainstorm waterlogging in sponge cities results from the interaction of risk, vulnerability, and recovery in dynamic changes [42,43]. Although humans still cannot resist inevitable natural hazards, risks can be reduced to a certain degree in terms of both vulnerability and resilience [18,19]. For example, (1) urban planners and managers should plan and incorporate disaster prevention and mitigation consciousness into urban planning and construction of risk aversion. When considering the nature and spatial layout of the parcel land, spatial location planning and construction land use design should be carried out reasonably according to the risk level of the disaster [13,35]. The change options that can be adopted include strengthening the construction of drainage facilities, setting a safe distance, changing the planning type of land use, and constructing engineering projects such as flood control land or cultural tourism projects such as parks and green spaces [16,44–47]. (2) The municipal department should strengthen the construction of drainage systems following the danger of waterlogging [34,35,42]. Measures that can be taken include rationally laying underground pipelines, constructing drainage pumping stations, treating urban inland rivers, and constructing sponge facilities used for infiltration reduction and accumulation [13,48,49]. Artificial sponges and other substances, such as highly permeable construction materials, are used to collect rainwater properly to reduce the risk of urban waterlogging [49]. (3) Focus on the flood-affected areas on both sides of the Nanmen River and Chishui River, where cultivated land and towns are relatively concentrated. It is necessary to strengthen engineering facilities for effective flood drainage and waterlogging prevention and take precautions against possible mountain floods, landslides, debris flows, and other hazards. Strengthen the construction of waterlogging prevention and drainage facilities in villages, towns, and farmland, such as building levees for flood control, flood discharge, drainage gates, and high-efficiency water-saving irrigation projects, to protect cultivated land and enhance flood control capabilities. Raise disaster risk awareness of residents and prepare for hazard prevention [18,50]. (4) The meteorological department shall timely forecast and warn of heavy rain hazards and establish monitoring, warning, and emergency response to heavy urban rain and waterlogging. In addition to flooding caused by heavy rain, the southeast coast of the SSCZ is susceptible to storm surges caused by typhoons [36]. It is recommended that river banks be built along the coast or mangroves or rice grass be planted to resist the impact of wind and waves [29].

Owing to the fact that the SSCZ is still in the preliminary stage of town-level administrative district development, but has an important strategic position to connect with the development artery in eastern Guangdong, the standard of waterlogging prevention will never be able to meet the demand for the future construction of sponge cities once the city moves into the fast track of development. The total annual runoff control rate of the SSCZ is required to be higher than 60% and lower than 85% [51]. However, the drainage pipe network facilities in the SSCZ are relatively imperfect, and the current standard for outdoor drainage facilities is just once a year. At present, the political and economic status of SSCZ is at a basic level, with a resident population of less than 200,000 and an equivalent economic scale of less than 400,000. It is determined that the sponge city planning standards of SSCZ need to effectively respond to no less than 20-year rainstorms [52,53]. However, as we

know, the planning of a sponge city can only look ahead, and the ecological function level of urban ecosystems must keep pace with the city's rapid development [15].

This study focused on the situation of overland flooding during heavy rain and waterlogging, which can guide the optimal layout of sponge city land construction. The following aspects need to be improved: (1) If the model were modified with the data of water points of prolonged waterlogging, the risk assessment results would be improved. (2) Urban underground drainage infrastructure systems, urban road planning, and other transmission equipment have an essential relationship with preventing and controlling rainstorms and waterlogging. (3) In addition, torrential rain and waterlogging in sponge cities are caused by many factors, including rainstorms, rivers, and storm surges. Disaster simulation of multiple flood sources such as rainstorms, rivers, and storm surges should be considered comprehensively.

5. Conclusions

In this study, taking the planning area of the SSCZ as an example, the SCS model was used to simulate the scenario of 100-year heavy rain events that lasted for 1 h. A neural network model was established to evaluate the land suitability of the sponge city. The results show that there are spatial differences among the land suitability of sponge cities in the SSCZ. The relatively suitable regions for construction (class IV and V), accounting for 73.59% of the entire area, with medium-high rain–flood resilience and moderate risk and vulnerability, are suitable for urban development site selection. It is suggested that they make full use of the natural sponges and strengthen their ecological function. The regions generally suitable for construction (class VI) account for 3.25% of the entire area, the most vulnerable. As the most densely constructed area in the SSCZ, it is necessary to strengthen the construction of artificial sponges and set up a safe distance for flooding. The regions less suitable for construction (class I, II), accounting for 3.3% of the entire area, are distributed along the Nanmen and Chishi River and its tributaries, with the highest risk of rainstorms and waterlogging and medium-low rain–flood resilience. The construction of flood control engineering should be strengthened. The regions for ecological construction (class III) account for 19.85% of the entire region, with low risk and low vulnerability. Priority should be given to protect the ecosystem of this area and exert the sponge function of isolation and ecological buffering.

From the perspective of the neural network model, this study verified the feasibility of the neural network method to evaluate the land suitability of sponge cities. The results of the criterion layer output from the RBF model, that is, the risk of environment, the vulnerability of the hazard-bearing body, and the rain–flood resilience of the sponge city, helped to eliminate the dimensional impact and obtain the overall judgment of the criterion layer. Based on this, the SOFM network was used to obtain the clusters of the target layer. The study area was divided into six classes, corresponding to four zones with different land suitability. The method, by using the neural network model, not only took into account the flooding hazard but also incorporated the ecological, social, and economic differences within the region into the land suitability evaluation framework. Furthermore, integrating GIS and neural networks can effectively solve data mining, analysis, visualization, and comprehensive application in planning and evaluation. Its application in land suitability evaluation under an ecological sponge city is relatively fruitful, and it is a scientific and feasible research method.

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