water

Article

Research on Runoff Management of Sponge Cities under Urban Expansion

Hongliang Sun [1], Shangkun Wu [2], Qiyu Dong [1], Xue Zhou [1], Jixian Yang [1,*] and Gang Li [2,*]

[1] State Key Laboratory of Urban Water Resource and Environment, School of Environment, Harbin Institute of Technology, Harbin 150090, China; dqylydia5175@163.com (Q.D.); hitzhouxue@126.com (X.Z.)
[2] College of Surveying and Mapping Engineering, Heilongjiang Institute of Technology, Harbin 150090, China; wsk15984231016@163.com
* Correspondence: yangxj@hit.edu.cn (J.Y.); ligang@hljit.edu.cn (G.L.)

Abstract: To integrate the sponge city concept into urban development, we propose an analytical approach for runoff volume control, considering urban expansion. Using Changchun City as a case study and historical land-use data, we simulated the prediction of Changchun City's land-use structure for 2035 change with the GeoSOS-FLUS platform. We calculated storage volumes for Low Impact Development (LID) designs using 2019 and 2035 land surface data. The objective is an 80% runoff volume control rate by 2035. Through Monte Carlo simulation and sensitivity analysis, we assessed the impact of various land-use types on LID storage volume calculations. Findings show that industrial land significantly influences LID storage volumes. This highlights the need for precise surveys of industrial land properties and surface composition in sponge city planning for more accurate runoff volume control analysis in Changchun City. The results indicate that LID storage volumes based on current data may not meet long-term sponge city goals due to increased impervious surfaces and runoff coefficients during urbanization.

Keywords: GeoSOS-FLUS; Monte Carlo; land use; Changchun City

check for updates

Citation: Sun, H.; Wu, S.; Dong, Q.; Zhou, X.; Yang, J.; Li, G. Research on Runoff Management of Sponge Cities under Urban Expansion. *Water* **2024**, *16*, 2103. https://doi.org/10.3390/w16152103

Academic Editor: Enrico Creaco

Received: 25 June 2024
Revised: 17 July 2024
Accepted: 24 July 2024
Published: 25 July 2024

1. Introduction

Since the initiation of the reform and opening-up policy, China has witnessed an impressive trajectory of socio-economic development, notably characterized by a rapid surge in the urbanization rate [1,2]. According to the data from the seventh national population census in 2021, the urbanization rate has attained 63.89%, reflecting a substantial increase of 14.21% compared to the figures recorded in 2010. Projections indicate a further ascent to 68% by the year 2050 [3]. The occurrence of urban waterlogging disasters typically results from precipitation exceeding the capacity limits of the urban drainage system, leading to ineffective drainage [4]. Historically, China employed relatively simple rainwater management methods, where a portion of the rainwater was absorbed by grasslands and trees, another part directly flowed into nearby rivers, lakes, and artificial reservoirs, and yet another part infiltrated the soil, percolating into underground rivers [5]. However, with the rapid expansion of cities and the increase in urban construction, natural drainage systems have gradually weakened, making them unable to meet the demands of urban drainage [6]. From 1978 to 2022, the percentage of China's permanent urban population increased from 17.92% to 65.20%, and the urban population grew more in 44 years than the United Kingdom achieved in 100 years of urbanization. Over the past decade, the permanent urban population increased by 236 million, and the urbanization rate rose by 14.21%, with an increment of 0.75%. The rapid expansion of urbanization has seen concrete roads replacing soil and grasslands, rivers being cut off, land being developed for commercial purposes, lakes being filled, and the storage capacity of water resources diminishing [7]. Taking Wuhan as an example, the number of lakes decreased from 127 in 1950 to 38 in 2016, with nearly two-thirds of the lakes disappearing [8]. The process of rainwater infiltration now requires the artificial construction of water channels to introduce water into drainage pipes, which then flow into retention basins [6]. The interception, filling of depressions, infiltration, and evaporation processes of urban surfaces for rainwater runoff have weakened. Coupled with the frequent occurrence of extreme weather in recent years [9], the resulting torrential rain and flood disasters are posing a serious threat to the normal operation of cities and the life and property safety of citizens [10,11].

To address the risk of flooding caused by rapid urbanization, China began drawing on advanced theories and experiences in stormwater management from abroad in 2010 [12]. Emphasizing the absorption and utilization of rainwater at its source, the country aimed to harmonize rainfall with urban water circulation [13]. In 2014, the Ministry of Housing and Urban-Rural Development issued the "Technical Guidelines for Sponge City Construction—Construction of Low-Impact Development Stormwater Systems (Trial)", advocating for the construction of sponge cities that naturally accumulate, infiltrate, and purify rainwater and recognizing the significant role that sponge city construction plays in enhancing urban resilience to flood disasters [14,15].

In the current context, with economic development as the central focus, the global process of urbanization is accelerating. However, the drawbacks of rapid urban modernization are becoming increasingly apparent [16–18]. The rapid transformation of urban land use types has led to significant changes in the natural and water cycling systems of cities [19]. It is generally acknowledged that the expansion of impervious surfaces during the urbanization process is a crucial factor [20]. This not only results in extensive land coverage but also involves the use of hard materials such as asphalt, concrete, and buildings, significantly reducing soil permeability [21,22]. As a result, rainfall has difficulty penetrating the ground quickly, leading to rapid surface runoff and a high susceptibility to flooding events [23–25]. Although urban planning can influence stormwater discharge systems, changes in urban land cover remain a key factor [26]. The reduction in surface roughness also triggers a series of changes related to water flow [27]. With the rapid expansion of global cities, phenomena such as droughts and urban flooding are becoming increasingly prominent, prompting researchers to contemplate urban water resource security. Ensuring an adequate water supply while reducing the risk of urban flooding hinges on the prudent utilization of rainwater resources [28]. In recent years, the annual occurrence of urban flooding and waterlogging disasters in Chinese cities has escalated, prompting an accelerated pace of sponge city construction to address urban waterlogging issues [29]. New concepts for stormwater management, such as Low Impact Development (LID) and Best Management Practices, along with China's Sponge City Program, have become essential means to reduce flooding disasters [30]. A sponge city is an urban development concept designed to sustainably manage water resources by absorbing, storing, infiltrating, and purifying rainwater through green infrastructure and water management practices. Low Impact Development (LID) is a land planning and engineering design approach that manages stormwater runoff by emphasizing on-site natural features and processes. Best Management Practices (BMPs) refer to structural, vegetative, or managerial strategies employed to treat, prevent, or reduce water pollution. Utilizing LID technologies, our objective is the seamless integration of ecosystem preservation with urban development. This initiative seeks to conserve or rejuvenate the natural landscape and its water regulation capabilities, thereby mitigating urban flooding and the correlated pollution, while simultaneously bolstering water supply [31]. Consequently, in developing nations, enhancing wastewater treatment environments is essential for refining the construction of urban drainage systems, specifically the water supply components. Nonetheless, the effective management of watershed systems necessitates the coordination of wastewater and urban runoff treatments [32]. In sponge city construction, urban water supply and drainage are separate components. However, through the interception and treatment of rainwater, the issue of water scarcity in cities can be addressed [33]. In the field of urban drainage, the discharge of pollutants into sewers may adversely affect the normal operation of sewer systems, the reliability of sewage treatment plants, and the protection of receiving water bodies [34]. Artificial wetlands possess excellent water absorption and storage capabilities, effectively regulating rainwater runoff and mitigating the flood risk from rainwater erosion [35]. Proper planning and utilization of artificial wetlands are crucial in sponge city construction [36]. The research of Bai et al. emphasizes the pivotal role of rhizospheric effects and wetland purification mechanisms. Concurrently, various methods for treating water pollutants exist, encompassing the implementation of absorption and utilization approaches [37]. With rapid urbanization, the increase in impervious surfaces in urban areas is a major cause of urban flooding and inundation [38]. Therefore, appropriate urban planning and stormwater management measures are needed to reduce the risks of urban flooding and inundation [39]. The exploration of expansion and future growth patterns is crucial for planning and managing cities [40]. Understanding past growth patterns and predicting future trends can help formulate policies better suited to addressing future challenges and opportunities [41]. It is essential to use Future Land Use Simulation (FLUS) software (V2.4)to simulate future land use scenarios [42], understand the characteristics of urban flood risk under different land use scenarios, and accurately predict urban flood risk [43]. Combining the Maximum Entropy model with FLUS predicts future flood-prone areas [44]. The study identifies impervious surfaces, population density, and green space ratio as key spatial driving factors behind urban waterlogging issues [9]. Using the Markov–FLUS model, three development scenarios for 2030 were simulated through Land Use and Land Cover (LULC) [45]. The economic priority scenario exhibits the highest risk of urban stormwater flooding disasters, while the sustainable development scenario has the lowest risk [46]. In the sustainable development scenario, an increase in green spaces, including forests, grasslands, and open water bodies, effectively reduces surface runoff and lowers the risk of stormwater flooding disasters. However, the reduction is limited as the recurrence interval of extreme rainfall events increases [47].

In the current context of sponge city planning and design, designing the storage capacity of LID facilities based only on the current situation cannot meet the needs of urban expansion. To solve this problem, this study derived the comprehensive runoff coefficient for the future city by simulating the future land use change scenarios and using the comprehensive runoff coefficient calculation method. The area and runoff coefficients of various land use types in Changchun City are the key parameters that affect the calculation of the total runoff control target. Sensitivity analysis by Monte Carlo analysis can determine the degree of influence of different land use types on the calculation results of the total runoff control target. It provides new ideas and decision support for sponge city planning and LID project development.

2. Materials and Methods

2.1. Study Area

Changchun City is the capital of Jilin Province (see Figure 1), located between 124°18′ and 127°02′ east longitude and 43°05′ and 45°15′ north latitude. With vast territory and abundant land resources, Changchun covers a total area of 20,604 km^2, including the urban area of 7661 km^2. Geographically, Changchun is situated at the junction of the Changbai Mountain Range and the Songliao Plain, with a generally south-high and north-low terrain. The predominant landforms are plateaus, accounting for 67.1% of the total area, followed by river valley plains at 22.6% and low hills at 10.3% [48]. The overall topography of the city is relatively flat, mainly consisting of plateaus and plains, with an average elevation of 206.6 m, a maximum elevation of 319 m, and a minimum elevation of 129 m. The overall slope is relatively gentle, with 85% of the area having slopes less than 0.05, and only 0.03% of the area having slopes greater than 25%. In general, Changchun is characterized as a plain-type city with both mountainous and hilly terrains. As of the end of 2022, the total population of Changchun City was 90.654 million, a decrease of 21,800 from the previous year. The urban resident population was 6.0868 million, accounting for 67.1% of the total population, with an increase of 0.3 percentage points. By the end of 2022, the birth population was 41,700, the birth rate was 4.59‰, the death population was 76,900, the death rate was 8.47‰, and the natural growth rate was −3.88‰. The gender ratio was

101.1. The climate of Changchun City is characterized as a temperate continental monsoon climate, with moderate dryness and four distinct seasons. The average annual temperature is 5.5 °C, and the maximum frozen soil thickness is 1.69 m. The prevailing wind direction is southwest, while northwest winds dominate in winter. The average annual wind speed is 4.4 m/s, with a maximum wind speed of 36.8 m/s. Based on meteorological data from Changchun City Meteorological Center for the years 1986–2015, the average annual precipitation in the past 30 years was 510 mm, and the average precipitation in the last decade was 556 mm. The average annual water surface evaporation reached 935.1 mm. Overall, the climate tends to be arid.

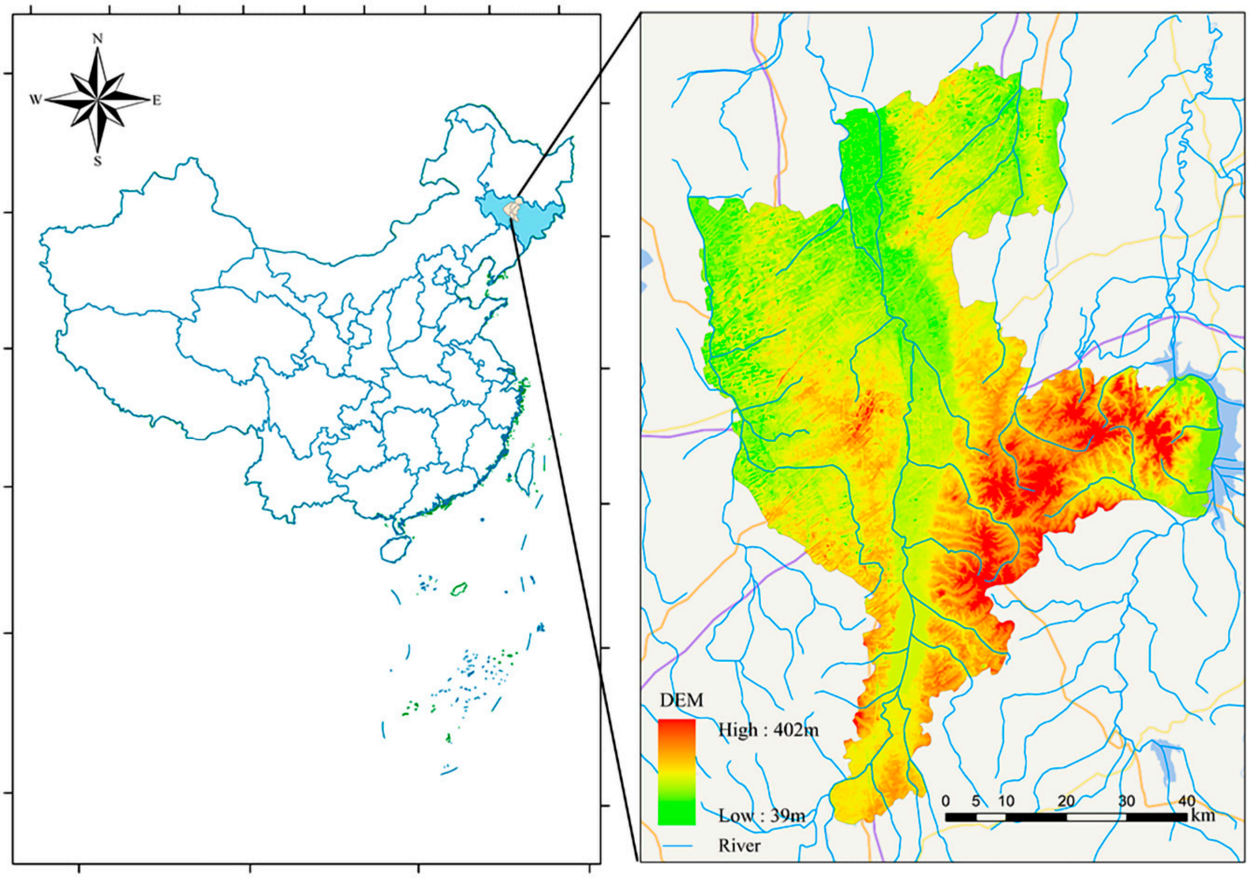

Figure 1. Elevation Map of the Study Area, Changchun City.

2.2. *Data Preprocessing and Preparation*

The remote sensing image data for Changchun City in 2011 and 2019 were acquired from Landsat 5 TM and Landsat 8 OLI/TIRS satellites, respectively, with a resolution of 30 m and cloud cover less than 5%. Elevation data were obtained from ASTER GDEM, also at a 30 m resolution, meeting the required level of detail. These remote sensing images and elevation data were obtained from the Geospatial Cloud Platform (https://www.gscloud.cn/ (accessed on 28 September 2023)). In addition, geospatial vector data, including administrative boundaries, railways, road networks, and water systems, were sourced from the National Geomatics Center of China (https://www.ngcc.cn/ (accessed 28 September 2023)). During the processing, these data were uniformly projected using the UTM projection method. Subsequently, the land-use types in the study area were categorized into cultivated land, forest land, grassland, water bodies, construction land, and unused land [49]. The Maximum Likelihood Classification algorithm was applied for supervised image classification [50]. To enhance simplicity and efficiency, post-classification refinement was performed to improve classification accuracy, and a confusion matrix was generated. The ArcGIS tool was utilized to compute the LULC change matrix, quantifying the conversion of a specific LULC category to another during the study period [51,52]. Finally, visual interpretation was employed to address mixed pixel issues, significantly improving the results of the supervised algorithm through visual analysis of reference data and local knowledge. Human visual interpretation was crucial for improving classification accuracy and the quality of the generated LULC maps. In the determination process based on topographic maps and high-resolution satellite images, the same method was applied to handle all misclassified pixels.

2.3. Study Methods

With the continuous advancement of urbanization, this paper takes Changchun City as an example, employing remote sensing technology and advanced GeoSOS-FLUS (V2.4) software to thoroughly analyze historical land use, predict future land use scenarios, and calculate the supplemental storage volume for LID designs in support of sponge city planning through Monte Carlo simulation for parameter sensitivity analysis.

2.3.1. Analysis Method for Historical Land Use Structure

With the support of the ENVI 5.3 platform, we meticulously preprocessed the remote sensing data from the Landsat series for the years 2011 and 2019. This preprocessing involved radiometric calibration, atmospheric correction, and cloud removal, aimed at minimizing errors introduced by factors like sensor characteristics, solar radiation, and atmospheric transmission. Following this, we employed a combination of supervised classification and manual visual interpretation, leveraging the actual spectral characteristics of land features in the study area. Through this method, we accurately classified the remote sensing images into six distinct land use types: cropland, forest land, grassland, water body, construction land, and unused land. The precise acquisition and thorough processing of the land use interpretation results for 2011 and 2019, along with data on land use changes, establish a robust foundation for subsequent analyses of land use changes. This meticulous approach contributes significantly to gaining a profound insight into the intricate evolution of the urban land use structure.

2.3.2. Methodology for Future Land Use Prediction

The future land use prediction model is a tool designed to anticipate potential scenarios of regional land-use changes based on the patterns of human activities and environmental evolution. The GeoSOS-FLUS (V2.4) software employed in this study is a secondary development based on the GeoSOS software. It primarily utilizes cellular automata as its fundamental mechanism, enabling the simulation of various land-use change scenarios under mutual influences of different land-use types. This software, relying on historical land-use data, employs a neural network algorithm to extract the suitability development probabilities for each land-use type, considering influential driving factors such as topography and transportation. These probabilities are then used to calculate the interconversion effects among different land-use types. Furthermore, during the phase of land-use change prediction, when conflicts arise in the appearance probabilities of multiple land-use types at a specific location, the model employs a competitive mechanism with a roulette wheel nature. This effectively reduces uncertainty and complexity in the prediction process, ensuring a higher simulation accuracy of the FLUS model. Given that current sponge city planning often targets the completion of sponge cities by the year 2035, this study can utilize the mentioned method, based on the land-use structure data of Changchun City in 2011 and 2019, to predict the land-use change scenarios for the year 2035 in Figure 2.

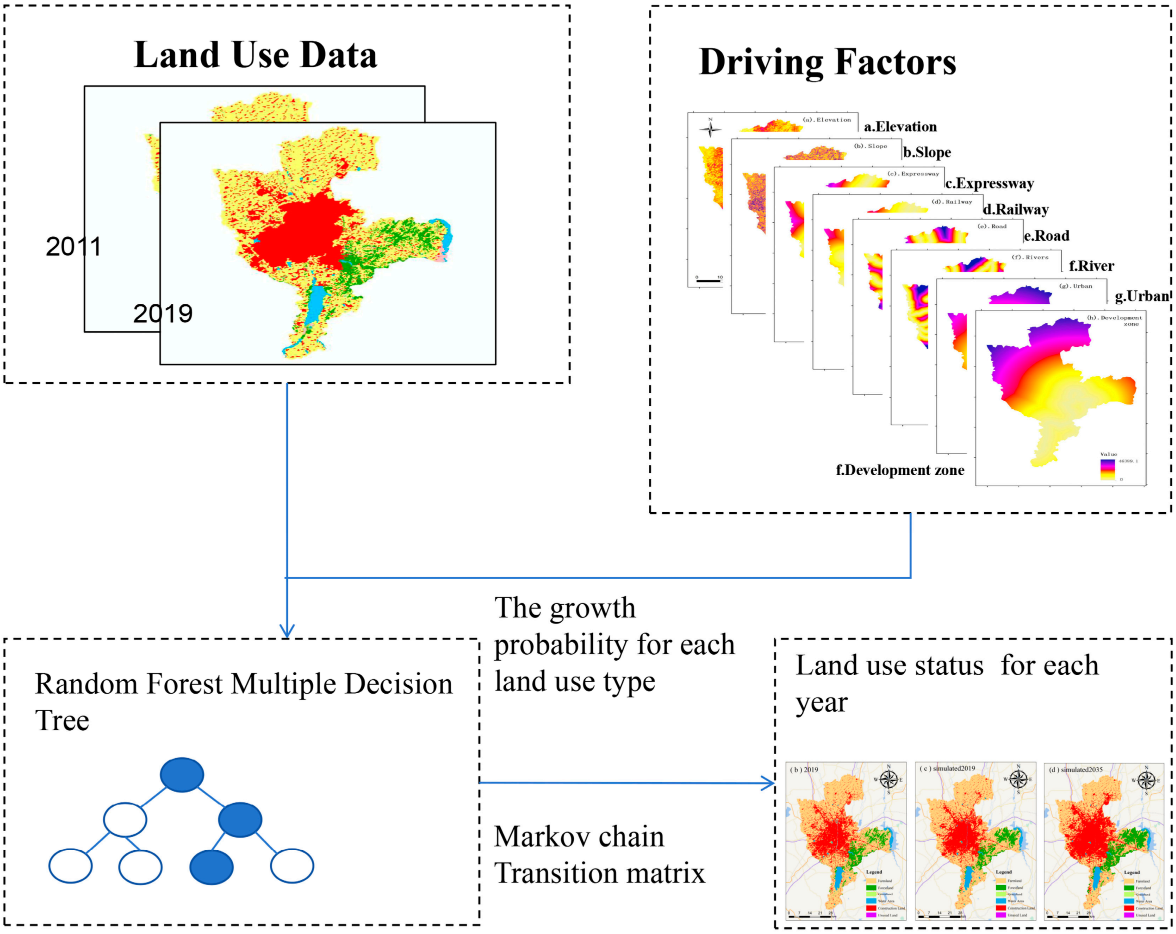

Figure 2. Flow chart of land use prediction.

2.3.3. Runoff Volume Control Target Calculation Method

The runoff volume control rate is a critical indicator in the construction of sponge cities in China, representing the proportion of annual rainfall that needs to be controlled. To provide scientifically reasonable control target values for sponge city construction in various cities, the "Guidelines" are based on historical rainfall statistics for nearly 200 cities in China. Alpha (α) in this context represents the annual runoff volume control rate. The mainland is divided into five zones based on the reasonable control range of the annual runoff volume control rate: Zone I (85% ≤ α ≤ 90%), Zone II (80% ≤ α ≤ 85%), Zone III (75% ≤ α ≤ 85%), Zone IV (70% ≤ α ≤ 85%), and Zone V (60% ≤ α ≤ 85%). The study area of Changchun City in this project is located in Zone II, corresponding to an annual runoff volume control rate control range of 80% to 85%. Therefore, this paper selects 80% as the minimum control target. Based on statistical rainfall data for Changchun City and the corresponding relationship between the annual runoff volume control rate and design rainfall as shown in Figure 3, the design rainfall range is determined to be 20.8 to 25.8 mm. In this study, a design rainfall of 20.8 mm is selected for calculation.

LID design storage volume represents the rainfall storage volume corresponding to a certain target of the annual runoff control rate. It is commonly used in sponge city planning and design, directly influencing the scale and investment of LID facilities. The calculation method for LID design storage volume can adopt the volume method:

$$V = 10HF\Psi \quad (1)$$

where H is the design rainfall (mm); V is the LID design storage volume (m^3); Ψ is the comprehensive runoff coefficient; F is the total area of the study area (ha).

The calculation method for the comprehensive runoff coefficient is as follows: based on the land use type analysis and predicted underlying surface data obtained for the study area, it is calculated by the weighted average of each land type's area using the following formula.

$$\Psi = \frac{\Sigma(F_i \cdot \varphi_i)}{F} \quad (2)$$

where i represents the i-th land use type; Ψ is the comprehensive rainfall-runoff coefficient; F is the total area of the study area (ha); Fi is the area of the i-th land use type (ha); φ_i is the rainfall-runoff coefficient of the i-th land use type.

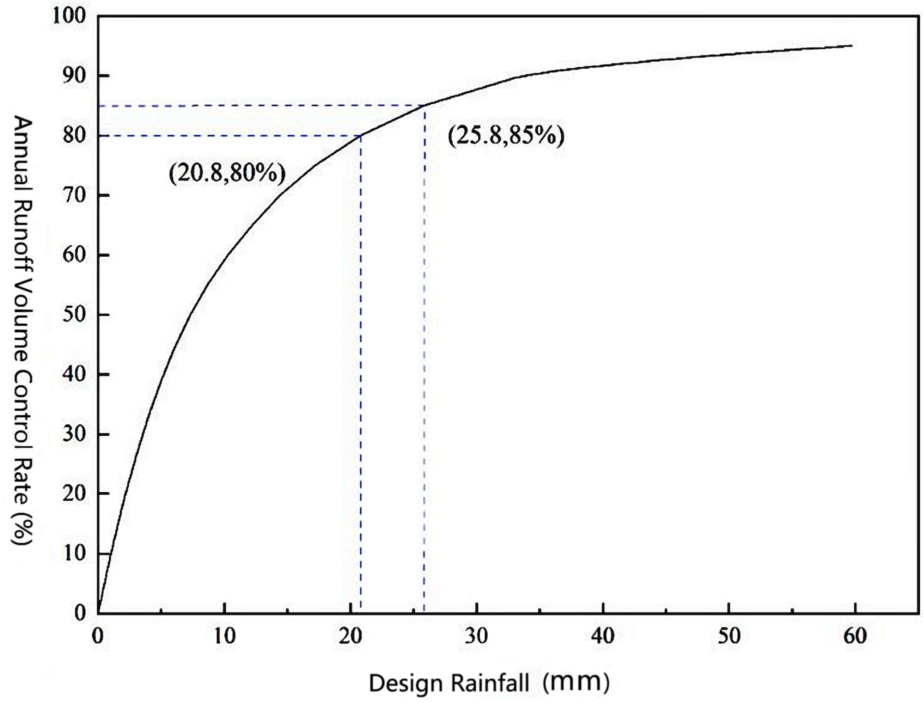

Figure 3. Correspondence Curve between Annual Runoff Volume Control Rate and Design Rainfall in Changchun City.

2.3.4. Sensitivity Analysis Method

The areas and runoff coefficients of various land use types in Changchun City, as analyzed in this study, are critical parameters influencing the calculation of runoff total control targets. Through parameter sensitivity analysis, the magnitude of the impact of different land use types on the results of runoff total control target calculations can be determined. In this study, we employed the Monte Carlo simulation method for sensitivity analysis [53], quantifying the influence of parameter fluctuations on model output results under variations in all parameters in the model input space. Monte Carlo simulation experiments were conducted using Crystal Ball software (11.1.3.0.0), developed by Oracle. Crystal Ball, an Excel-based data simulation and analysis tool, is widely used for predicting mathematical models and analyzing parameter uncertainties. The software allows for the exploration of model operating mechanisms and facilitates discussions and analyses of generated results. In the process of parameter uncertainty analysis, users can define the distribution forms of model variables, including normal distribution, uniform distribution, etc., based on their specific needs. The version of Crystal Ball software utilized in this study is 11.1.2.4.

3. Results

3.1. Land Use Change

3.1.1. Historical Land Use Basic Data of Changchun City

This article conducts an in-depth analysis of the land use situation in Changchun City for the years 2011 and 2019. Figure 4 vividly illustrates the notable changes in both the structure and scale of land use during these two years. The construction land in the primary urban area exhibits a continuous outward expansion trend, while the surrounding farmland is consistently diminishing, particularly noticeable in the southern part of the city. Here, the reduction of farmland is more pronounced. The city's expansion not only leads to an augmented construction land area but also triggers a substantial conversion of farmland into urban construction land. Simultaneously, the construction of new urban public green spaces, green corridors, and similar initiatives results in a slightly increasing trend in grassland area within the expanding regions. Meanwhile, forest land, water areas, and unused land remain essentially unchanged. Broadly speaking, from 2011 to 2019, Changchun City's land use pattern demonstrates a discernible trend of hardening, accompanied by a decrease in the comprehensive runoff coefficient, thereby elevating the risk of urban waterlogging disasters. This study profoundly unravels the intricacies of urban land use evolution, providing crucial references and decision support for future urban planning and disaster prevention and mitigation in a scientifically oriented manner.

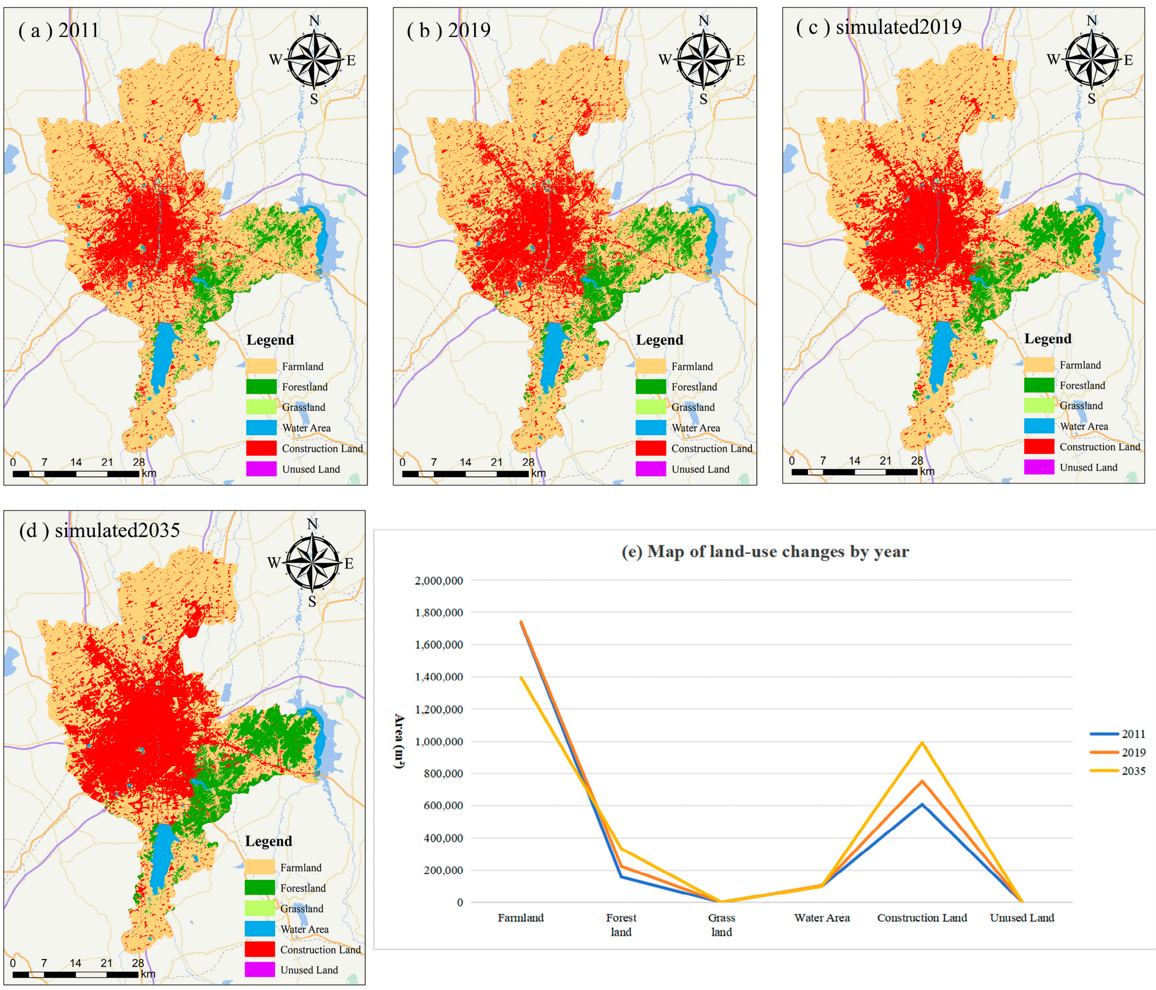

Figure 4. Land Use Structure Data for Changchun City in 2011, 2019, simulated 2019, and 2035.

3.1.2. Future Land Use Evolution Prediction for Changchun City

Drawing upon the land use conditions in Changchun City during 2011 and 2019 as foundational data, a predictive model for future land use is constructed to forecast trends up to 2035.

Initially, the FLUS model is established, incorporating actual circumstances in Changchun City. Comprehensive analysis is conducted by selecting indicators highly correlated with land use changes from both natural and locational perspectives. The driving factors for land use simulation, encompassing elevation, slope, water systems, urban areas, development zones, roads, highways, and railways, are then extracted (Figure 5). Employing an artificial neural network model, the FLUS model utilizes machine learning methods to discern interaction effects and mapping relationships between spatial independent variables (land use change driving factors) and spatial dependent variables (historical land use data). This model calculates the potential likelihood of various land use types undergoing transitions on each cell, thereby obtaining suitability development probabilities for various land use types in the study area. Finally, the FLUS model is applied using Changchun City's 2011 land use data, simulating the land use situation in 2019. Upon verification against the actual land use situation in 2019, the model demonstrates a high level of consistency with a Kappa coefficient of 0.789 and an overall accuracy of 0.875. This indicates that the constructed FLUS model effectively meets the requirements for simulating future land use changes in Changchun City.

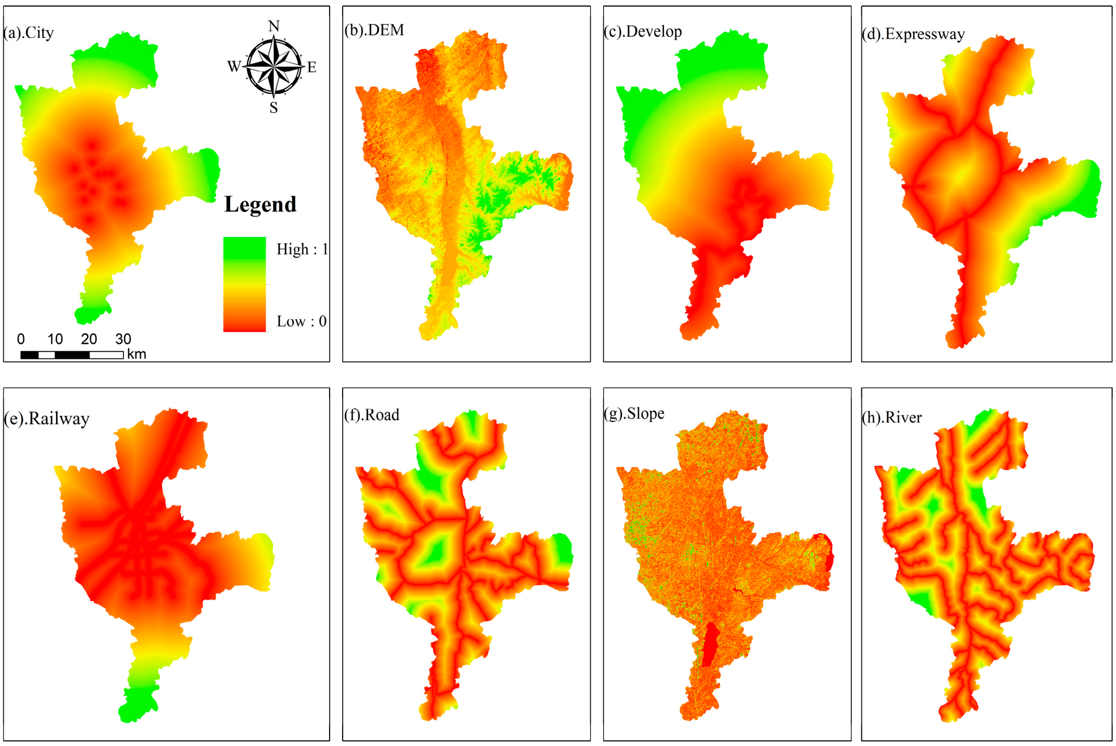

Figure 5. Driving factors for land use simulation.

Subsequently, the FLUS model's adaptive inertia mechanism-based cellular automaton module is employed. Model parameters, including the neighborhood factor, adaptive inertia coefficient, and conversion rules, are set. These parameters, combined with suitability development probabilities, collectively determine the overall conversion probability of cells. The spatial configuration of urban land use is achieved through the roulette mechanism, resolving interactive competition relationships between different land classes. The simulated results for Changchun City's land use in 2035 are presented in Figure 4. From 2019 to 2035, the city's expansion will perpetuate the trend of increasing hardened surfaces observed from 2011 to 2019. The city's boundaries will continually extend, with a significant amount of farmland converting into hard surfaces such as construction land. Permeable surfaces, such as grassland and forestland, will experience slow growth, while water bodies and unused land will remain relatively stable. This observation underscores that the process of urban development inevitably results in a substantial increase in hardened areas, leading to an escalating overall runoff coefficient. Consequently, this weakens the city's rainwater control capacity, further diminishing its flood control and drainage capabilities.

3.2. Analysis of Runoff Total Control Objectives in Changchun Sponge City Construction

3.2.1. Comprehensive Perspective of Changchun City for Runoff Total Control Objectives

Considering the historical analysis and future predictions of land use changes in Changchun City, the calculations are based on the entire area of Changchun City. Subsequently, this study determined the comprehensive runoff coefficient for the entire area of Changchun City to be 0.38 in 2019 and 0.42 in 2035. Achieving an annual runoff total control rate of 80% corresponds to LID design storage volumes of 24.21 million m^3 and 26.56 million m^3 for the years 2019 and 2035, respectively.

Considering the development patterns and planning realities, the current focus of sponge city construction in existing urban areas is primarily on the main urban districts. The construction of sponge features in rural areas, characterized by natural permeable underlays such as farmland and woodland, lacks necessity and feasibility. Therefore, this paper, based on Changchun City's administrative boundaries and actual development, designates the main urban area as the subject for deriving runoff total control objectives and studying sponge city planning.

A comparative analysis of land use distribution in the main urban area of Changchun City in 2019 and 2035 reveals significant changes. From 2019 to 2035, as urbanization steadily progresses, the area of farmland undergoes a substantial reduction, decreasing by 7614.8 ha, with the majority being converted into construction land. Correspondingly, the area of construction land increases from 32,113.4 ha in 2019 to 39,882.4 ha in 2035, representing a 24.2% growth. Simultaneously, there are minor reductions in the areas of woodland, grassland, and unused land, with decrease rates of 3.2%, 0.5%, and 4.5%, respectively. See Table 1.

Table 1. Simulation Results of Land Use Evolution and Changes in Annual Runoff Control Objectives in the Main Urban Area of Changchun City.

Year	Area of Various Land Use Types (ha)						Comprehensive Runoff Coefficient for the Current Situation	Current Annual Runoff Control Rate (%)	LID Design Storage Volume (Ten Thousand m^3)
	Farmland	Forest Land	Grass Land	Water Area	Construction Land	Unused Land			
2019	19,306.8	2341.5	12,411.1	1759.1	32,113.4	453.5	0.51	59.9	720.7
2035	11,692.0	2267.5	12,351.4	1759.1	39,882.4	433.0	0.57	55.8	809.8
Changed area	−7614.8	−74.0	−59.7	0.0	7769.0	−20.5	0.06	−4.1	89.1
Rate of change	−39.4%	−3.2%	−0.5%	0.0%	24.2%	−4.5%	12.4%	−6.8%	12.4%

In general, the land use changes in the main urban area of Changchun City exhibit a persistent trend of surface hardening. Permeable surfaces, such as farmland, forest land, grassland, and unused land, gradually diminish, transforming into hardened surfaces, primarily construction land. This contributes to an elevated risk of urban heavy rainfall and flood disasters. Simultaneously, in 2019, to achieve an 80% annual runoff control rate, the planned LID design storage volume for the main urban area of Changchun City should be 7.207 million m^3. Due to urbanization demands, the continuous hardening of the underlying surface in Changchun City's main urban area results in an increase in the comprehensive runoff coefficient from 0.50 in 2019 to 0.54 in 2035. To meet the requirements of building a sponge city in the future, the required LID design storage volume should reach 7.738 million m^3, an 8.2% increase compared to 2019. In sponge city planning and construction, if the total storage volume of planned sponge facilities is based on the runoff control target of 2019, it will lead to a runoff control rate in Changchun City below the 80% construction requirement in 2035. Therefore, the results of this study indicate that the planning and construction of sponge cities should fully consider the results of future urban expansion and land evolution. Planning objectives for sponge facilities should be set at future time points to meet the long-term needs of urban development.

3.2.2. Runoff Control Comparison in Old and New Changchun Urban Areas

We selected the Erdao Watershed and the Fuyu River Watershed in Figure 6. There are two river systems in the urban area of Changchun; one is the Yitong River, and the other is the Xinkai River. The Erdao River basin belongs to the Yitong River, and the Fuyu River basin belongs to the Xinkai River. The Xinkai River is the largest tributary of the Yitong River, the second Songhua River system. The Yitong River is located at the western edge of the development zone and flows from south to north across the city. The catchment area of the Yitong River in Changchun is 5412.8 km^2, accounting for 26.58% of the city's total area. The riverbed is 15–30 m, the average width of the river is 15 m in the dry season, the slope is 0.24%, and the average runoff is 4.0 × 108 m^3. The total length of the Yitong River is 283 km, and the watershed area is 7515 km^2. As representative study areas for the old and new urban areas of Changchun City, respectively, this study explores the evolution of land use types from 2019 to 2035 and analyzes runoff control targets. Taking the Erdao Watershed as an example of the old urban area, in addition to a small amount of existing farmland or unused land being transformed into hardened surfaces dominated by construction land, forest land, grassland, and water bodies remain unchanged. From 2019 to 2034, the existing 109.2 ha of farmland disappeared, with a reduction of 98.8%, and construction land correspondingly increased from 2842.8 ha in 2019 to 2950.9 ha, a growth rate of 3.8%. At the same time, the comprehensive runoff coefficient increased from 0.60 to 0.61, and the current annual runoff control rate decreased from 53.9% to 53.1%. To meet the 80% annual runoff control rate, the planned LID design storage volume increased slowly from 453,000 m^3 in 2019 to 461,000 m^3 in 2035, with little change. See Table 2.

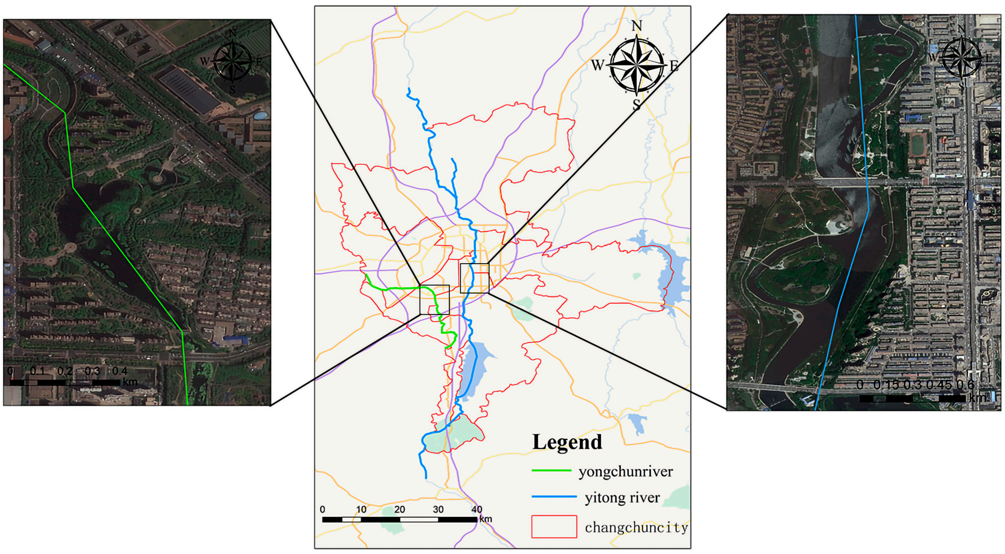

Figure 6. Erdao Watershed and the Fuyu River Watershed.

Table 2. Land Use Evolution and Changes in Annual Runoff Control Targets in the Erdao Watershed.

Year	Area of Various Land Use Types (ha)						Comprehensive Runoff Coefficient for the Current Situation	Current Annual Runoff Control Rate (%)	LID Design Storage Volume (Ten Thousand m^3)
	Farmland	Forest Land	Grass Land	Water Area	Construction Land	Unused Land			
2019	109.2	77.1	548.2	54.3	2842.8	17.7	0.67	46.6	51.1
2035	1.3	77.1	548.1	54.3	2950.9	17.7	0.69	44.3	52.3
Rate of change	−98.8%	−0.1%	0.0%	0.0%	3.8%	0.0%	2.4%	−5.0%	2.4%

In the context of a new urban area, the land use in the Fuyu River watershed undergoes significant changes from 2019 to 2035, mainly characterized by a substantial reduction in permeable surfaces, such as farmland, and a large increase in impervious surfaces, including built-up areas. Specifically, the farmland area decreases from 1542.1 ha in 2019 to 525.9 ha in 2035, representing a reduction of 65.9%. The built-up area increases from 1738.8 ha to 2768.5 ha, showing a growth of 59.2%. Additionally, there is a slight decrease in both forestland and grassland, by 0.6% and 1.8%, respectively. The comprehensive runoff coefficient increases from 0.48 to 0.57, indicating a significant increase in surface hardening. Consequently, to achieve the 80% annual runoff control rate target, the planned LID design storage volume increases from 41.4 million m^3 in 2019 to 49.0 million m^3 in 2035, demonstrating a growth rate of 18.4%.

Overall, compared to the old urban areas represented by the Erdao River watershed, where reconstruction may be challenging due to high building density and significant surface hardening, land use types remain mostly unchanged or experience minor variations from 2019 to 2035. In contrast, the new urban areas, represented by the Fuyu River watershed, exhibit substantial changes in land use types during the same period. This is attributed to lower urbanization levels, a larger area of farmland, and significant potential for urban development. With urban expansion and development, a considerable amount of permeable surfaces transforms into impervious surfaces between 2019 and 2035. This results in a decrease in soil permeability to rainwater, reflected in a notable increase in both the comprehensive runoff coefficient and the annual runoff control rate and a decrease in the LID design storage volume. Therefore, the LID design storage volume, based on the 2019 land use type plan, is insufficient to meet the runoff control target for 2035. See Table 3.

Table 3. Land Use Evolution and Changes in Annual Runoff Control Targets in the Fuyu River Watershed.

Year	Area of Various Land Use Types (ha)						Comprehensive Runoff Coefficient for the Current Situation	Current Annual Runoff Control Rate (%)	LID Design Storage Volume (Ten Thousand m^3)
	Farmland	Forest Land	Grass Land	Water Area	Construction Land	Unused Land			
2019	1542.1	9.9	750.4	67.0	1738.8	23.8	0.48	61.6	40.9
2035	525.9	9.8	736.9	67.0	2768.5	23.8	0.61	52.7	52.7
Rate of change	−65.9%	−0.6%	−1.8%	0.0%	59.2%	0.0%	28.9%	−14.5%	28.9%

3.3. Sensitivity Analysis of Construction Land Structure on Runoff Control Target Calculation

In the computation of the LID design storage volume for Changchun's main urban area, the primary focus lies in the planning and design of sponge cities, specifically targeting construction land in the main urban area. Utilizing the 2016 statistical data on urban land use nature in Changchun and the "Classification and Planning Construction Land Standards for Urban Land Use", this study categorizes construction land into nine types (e.g., residential land, public land, commercial land, etc.). The runoff coefficients for each land type and their respective proportions in construction land were meticulously estimated (Table 4). To dissect the impact of each construction land type on the LID design storage volume calculation, a Monte Carlo analysis was deployed. Under the assumption that each parameter (construction land type) follows a normal distribution within its fluctuation range, as outlined in Table 5, the relative importance of each parameter in influencing the final result was discerned through 10,000 iterations of Monte Carlo simulation [54].

As depicted in Figure 7, in the sensitivity analysis of LID design storage volume concerning runoff coefficients and the proportion of construction land, the sensitivity of industrial land ranks the highest, closely followed by residential land. This stems from the fact that industrial land exhibits a relatively substantial proportion of impermeable surfaces like factory buildings and paved roads, coupled with lower requirements for green coverage. Consequently, the construction of permeable natural surfaces such as green spaces tends to be overlooked, leading to an elevated overall runoff coefficient. Since the proportion of industrial land is second only to residential land, the uncertainty associated with industrial land parameters has the most substantial impact on the results of LID design storage volume in both sensitivity analyses. This underscores the necessity for a detailed and precise survey of the proportion and composition of underlying surfaces of industrial land in the city to achieve more accurate results in analyzing runoff control targets.

Table 4. Land Use Structure and Runoff Coefficient Estimation in 2035 for the Main Urban Area of Changchun City.

Land Use Type	Proportion of Construction Land (%)	Area (ha)	Runoff Coefficient
Arable Land	—	11,692	0.25
Forest Land	—	2268	0.15
Water Area	—	1759	0.15
Residential	28%	14,626	1
Public	9%	4701	0.56
Commercial	5%	2612	0.66
Industrial	25%	13,059	0.71
Logistics and Warehousing	3%	1567	0.71
Road and Transportation	16%	8357	0.68
Public Facilities	5%	2612	0.64
Green Space and Plaza	7%	3656	0.29
Special Use	2%	1045	0.58
Unused Land	—	433	0.35

Table 5. Fluctuation Range of Construction Land Structure and Runoff Coefficient.

Land Use Type	Proportion of Construction Land (%)	Runoff Coefficient
Residential	28~31	0.57~0.65
Public	9~10	0.55~0.63
Commercial	4~5	0.64~0.74
Industrial	22~25	0.7~0.8
Logistics and Warehousing	2~3	0.7~0.8
Road and Transportation	15~16	0.66~0.77
Public Facilities	4~5	0.63~0.72
Green Space and Plaza	7~8	0.27~0.32
Special Use	2~3	0.57~0.65

In the contemporary realm of sponge city planning and design, the primary focus tends to revolve around residential communities, urban road networks, and park squares. However, there is a noticeable dearth of comprehensive research and established design standards pertaining to the transformation of industrial zones within the ambit of low-impact development for sponge cities [55]. The findings derived from this study offer valuable insights into the realm of sponge city construction. Industrial areas, characterized by expansive spatial footprints, exhibit relatively lower coordination challenges in terms of transformation when juxtaposed with residential zones. Not only do these industrial areas present opportunities for cost-effective refurbishment and landscape enhancements, but the majority of them also boast favorable conditions for transformation. The potential impact of such transformations on sponge city construction indicators is substantial. Consequently, it is imperative to undertake comprehensive research and formulate pertinent standards for the transformation of industrial land within the context of sponge cities.

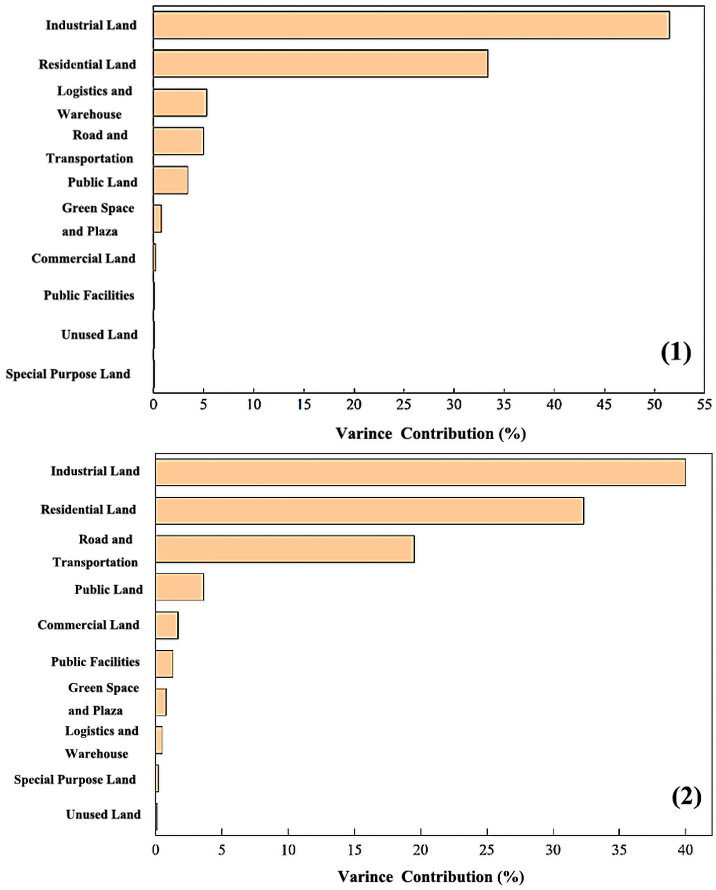

Figure 7. The sensitivity analysis results of different factors. (**1**) shows the sensitivity of LID Design Storage Volume to Runoff Coefficients; (**2**) shows the sensitivity of LID Design Storage Volume to Land Use Proportions.

4. Discussion

4.1. Impact of Land Changes on Runoff Control in Sponge Cities

Building upon the preceding analysis, this section addresses the following questions: How can long-term development goals for sponge city initiatives be systematically planned, considering future changes in urban land use due to city development? Although simulations and predictions of urban land use changes are commonly used in domestic and international research to assess the risk of urban rainstorms and flood disasters, their application in sponge city planning and design is limited. Therefore, using Changchun City as a case study, this paper focuses on designing low-impact development (LID) facilities to achieve an 80% annual runoff control rate in Changchun City by 2035. LID design storage volume represents the rainfall storage volume required to meet a specific annual runoff control rate target. This metric is essential in sponge city planning and design, as it directly affects the scale and investment of LID facilities. The LID design storage volume calculation can utilize the volume method: The comprehensive runoff coefficient is calculated based on land use type analysis and predicted underlying surface data for the study area, using the weighted average of each land type's area.

The application of Monte Carlo simulation and sensitivity analysis in our study plays a pivotal role in addressing the uncertainties and sensitivities associated with predicting LID design storage volumes and runoff control targets. Sensitivity analysis complements this by identifying the relative importance of each input parameter on the predicted outcomes. We can rank the parameters based on their influence by systematically varying one parameter at a time and evaluating its impact. This helps pinpoint the most critical factors that need careful consideration, enhancing our predictions' robustness and reliability. They provide a scientifically sound basis for decision-making, facilitating the systematic advancement of sustainable urban water management practices.

The systematic and comprehensive advancement of sponge city construction implies that the construction of sponge cities is no longer an isolated task in specific regions of a city. The concept of sponge city construction needs to be thoroughly integrated into the dynamic process of urban development. Presently, the planning of sponge city construction in various cities generally lacks foresight. When formulating long-term development goals for sponge city construction, most cities often overlook the dynamic development of urban land boundaries and land use types [55]. In the long run, the development process of a city will inevitably lead to an increase in the degree of impervious surface. Planning for the long-term development of sponge cities based on the current urban scale and land use types may raise the following issues: (1) Underestimating the future expansion of city boundaries and the increase in the degree of impervious surfaces, resulting in sponge city construction schemes that fail to meet the requirements of targets such as runoff control, leading to an increase in the risk of urban rainstorm and flooding disasters. (2) Overestimating the changes in land use and the increase in the degree of impervious surfaces brought about by urban development. Based on this, overly ambitious runoff control targets are set, resulting in large-scale facilities, wasteful investments, and problems such as excessive collection of rainwater leading to the shrinkage of urban water bodies.

Lack of overall and comprehensive planning when formulating sponge city plans or regional low-impact development schemes. Many planning projects tend to focus on specific aspects, such as flood risk management or urban greening, neglecting the complex interactive relationships within the urban system. This decentralized approach may lead to a range of problems, including resource waste, planning conflicts, and the inability to fully achieve the city's sustainability goals.

4.2. Limitations and Future Prospects

This study has enhanced our comprehension of runoff control in sponge cities amidst urban expansion and changing land use. However, it is crucial to acknowledge certain limitations. Firstly, the selected study area represents a singular, rapidly urbanizing city, necessitating further research and discussion to generalize the findings to other global cities. Secondly, identifying appropriate driving factors for simulating future land-use scenarios and accounting for the multifaceted influences on the urbanization process, including policy, economic, and social factors, requires a more nuanced investigation. A more detailed on-site investigation is imperative to comprehensively understand runoff control in sponge cities and refine sponge city planning during urban expansion.

Additionally, the model constructed in this paper relies on assumptions, such as estimates for the increase in impervious surfaces and runoff coefficients during future urbanization processes. These assumptions impact the accuracy and reliability of the model, prompting the need for future research to optimize the model for more accurate simulations of dynamic changes in the urbanization process. Subsequent studies could benefit from improved data quality through precise and comprehensive data collection and processing. In urban planning, this study's identified limitations open avenues for future work, emphasizing in-depth research across various urban cases, consideration of multiple factors, and the derivation of more universally applicable and reliable conclusions.

5. Conclusions

This paper offers a comprehensive examination of prevalent methodologies for assessing urban flood risk based on land-use changes. It presents an innovative approach, forecasting future urban land-use scenarios by leveraging current land-use conditions. The objective is to furnish precise and detailed insights into the proportion of industrial land and its underlying surface composition for sponge city planning in Changchun. The new method employs Monte Carlo simulation and, through sensitivity analysis, explores the potential impact of proportions of various land-use types and their runoff coefficients on the calculation results of LID design storage volume in Changchun's construction land. The primary research findings are outlined as follows:

(1) Utilizing the GeoSOS-FLUS software platform and grounded in the surface conditions of Changchun in 2011 and 2019, we developed a predictive model for future land use, simulating the 2035 land-use data for Changchun. The results indicate a consistent trend of surface hardening, leading to a reduction in the overall runoff coefficient and an escalation in the risk of urban flooding amid Changchun's urbanization.

(2) With the sponge city construction goal set at an 80% control rate for annual runoff in 2035 (a design rainfall of 20.8 mm), we calculated the LID design storage volume as 77.38 million m^3 based on the 2035 surface data. In comparison to the LID design storage volume based on the 2019 surface data, this represents an 8.2% increase, affirming the imperative nature of integrating future land-use predictions into the analysis of runoff control objectives.

(3) By employing the Monte Carlo simulation method to conduct sensitivity analyses on the land-use proportions and runoff coefficients in construction land, we observed that the sensitivity of LID design storage volume to industrial land is the highest. This underscores the necessity for thorough and accurate investigations into the proportion of industrial land and its underlying surface composition for sponge city planning in Changchun.

Therefore, the conclusions of this study can be summarized as follows: the phenomenon of surface hardening in the main urban area of Changchun is significant. Particularly, permeable surfaces, such as farmland and forests near rural areas, as well as grasslands and unused land in the main urban area, are gradually being replaced by impermeable surfaces like concrete and asphalt from construction activities. This results in a reduction in the roughness of urban surfaces, increasing the risk of flash floods during heavy rainfall. The anticipated future urban expansion will further intensify the demand for construction land, necessitating rational planning and control. As the urban surfaces continue to harden, the overall runoff coefficient has increased from 0.50 in 2019 to 0.54 in 2035. Consequently, the planned LID facility design storage volume should be adjusted from the initial 720.7 million m^3 to 773.8 million m^3. In sensitivity analysis, industrial land exhibits the highest sensitivity, followed by residential land for urban residents.

Author Contributions: Conceptualization, H.S. and J.Y.; methodology, H.S. and X.Z.; software, S.W.; data curation, G.L.; writing—original draft preparation, S.W.; writing—review and editing, J.Y. and Q.D.; visualization, X.Z.; supervision, G.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by State Key Laboratory of Urban Water Resource and Environment (Harbin Institute of Technology) (No. 2024TS16) and the Fundamental Research Funds for the Central Universities (No. HITDZJJ.2023059).

Data Availability Statement: All data generated or analyzed during this study are included in this published article.

Acknowledgments: The authors express their sincere gratitude for the warm work of the editor and the anonymous reviewers.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Guan, X.; Wei, H.; Lu, S.; Dai, Q.; Su, H. Assessment on the urbanization strategy in China: Achievements, challenges and reflections. *Habitat Int.* **2018**, *71*, 97–109. [CrossRef]
2. Peng, K.; He, X.; Xu, C. Coupling coordination relationship and dynamic response between urbanization and urban resilience: Case of Yangtze river delta. *Sustainability* **2023**, *15*, 2702. [CrossRef]
3. Qian, Y.; Wang, H.; Wu, J. Protecting Existing Urban Green Space versus Cultivating More Green Infrastructures: Strategies Choices to Alleviate Urban Waterlogging Risks in Shenzhen. *Remote Sens.* **2021**, *13*, 4433. [CrossRef]

4. Yang, Y.; Pan, C.; Fan, G.; Tian, M.; Wang, J. A New Urban Waterlogging Simulation Method Based on Multi-Factor Correlation. *Water* **2022**, *14*, 1421. [CrossRef]
5. Sobieraj, J.; Bryx, M.; Metelski, D. Stormwater Management in the City of Warsaw: A Review and Evaluation of Technical Solutions and Strategies to Improve the Capacity of the Combined Sewer System. *Water* **2022**, *14*, 2109. [CrossRef]
6. Yu, Q.; Sun, Z.; Shen, J.; Xu, X.; Han, Q.; Zhu, M. The nonlinear effect of new urbanization on water pollutant emissions: Empirical analysis based on the panel threshold model. *J. Environ. Manag.* **2023**, *345*, 118564. [CrossRef]
7. Wang, G.; Xiao, C.; Qi, Z.; Meng, F.; Liang, X. Development tendency analysis for the water resource carrying capacity based on system dynamics model and the improved fuzzy comprehensive evaluation method in the Changchun city, China. *Ecol. Indic.* **2021**, *122*, 107232. [CrossRef]
8. Du, N.; Ottens, H.; Sliuzas, R. Spatial impact of urban expansion on surface water bodies—A case study of Wuhan, China. *Landsc. Urban Plann.* **2010**, *94*, 175–185. [CrossRef]
9. Qin, Y. Urban flooding mitigation techniques: A systematic review and future studies. *Water* **2020**, *12*, 3579. [CrossRef]
10. Han, J.; Wang, C.; Deng, S.; Lichtfouse, E. China's sponge cities alleviate urban flooding and water shortage: A review. *Environ. Chem. Lett.* **2023**, *21*, 1297–1314. [CrossRef]
11. Sun, X.; Zhang, H.; Hua, D.; Wei, B. The influence of urbanization on storm runoff. In *Proceedings of the IOP Conference Series Earth Environmental Science*; IOP Science: Bristol, UK, 2021; p. 022031.
12. Ji, L.; Rao, F. Comprehensive Case Study on the Ecologically Sustainable Design of Urban Parks Based on the Sponge City Concept in the Yangtze River Delta Region of China. *Sustainability* **2023**, *15*, 4184. [CrossRef]
13. Xia, J.; Zhang, Y.; Xiong, L.; He, S.; Wang, L.; Yu, Z. Opportunities and challenges of the Sponge City construction related to urban water issues in China. *Sci. China Earth Sci.* **2017**, *60*, 652–658. [CrossRef]
14. Li, J.; Jiang, Y.; Zhai, M.; Gao, J.; Yao, Y.; Li, Y. Construction and application of sponge city resilience evaluation system: A case study in Xi'an, China. *Environ. Sci. Pollut. Res. Int.* **2023**, *30*, 62051–62066. [CrossRef]
15. Nguyen, T.T.; Ngo, H.H.; Guo, W.; Wang, X.C.; Ren, N.; Li, G.; Ding, J.; Liang, H. Implementation of a specific urban water management-Sponge City. *Sci. Total Environ.* **2019**, *652*, 147–162. [CrossRef]
16. Chen, M.; Liu, W.; Tao, X. Evolution and assessment on China's urbanization 1960–2010: Under-urbanization or over-urbanization? *Habitat Int.* **2013**, *38*, 25–33. [CrossRef]
17. Gao, Y.; Shen, Z.; Liu, Y.; Yu, C.; Cui, L.; Song, C. Optimization of differentiated regional land development patterns based on urban expansion simulation—A case in China. *Growth Chang.* **2023**, *54*, 45–73. [CrossRef]
18. Kong, F.; Sun, S.; Lei, T. Understanding China's urban rainstorm waterlogging and its potential governance. *Water* **2021**, *13*, 891. [CrossRef]
19. Hu, J.; Wu, Y.; Wang, L.; Sun, P.; Zhao, F.; Jin, Z.; Wang, Y.; Qiu, L.; Lian, Y. Impacts of land-use conversions on the water cycle in a typical watershed in the southern Chinese Loess Plateau. *J. Hydrol.* **2021**, *593*, 125741. [CrossRef]
20. Zhang, Z.; Wei, Y.; Li, X.; Wan, D.; Shi, Z. Study on Tianjin Land-Cover Dynamic Changes, Driving Factor Analysis, and Forecasting. *Land* **2024**, *13*, 726. [CrossRef]
21. Scalenghe, R.; Marsan, F.A. The anthropogenic sealing of soils in urban areas. *Landsc. Urban Plan.* **2009**, *90*, 1–10. [CrossRef]
22. Wałęga, A.; Radecki-Pawlik, A.; Cupak, A.; Hathaway, J.; Pukowiec, M.J.W. Influence of changes of catchment permeability and frequency of rainfall on critical storm duration in an urbanized catchment—A case study, Cracow, Poland. *Water* **2019**, *11*, 2557. [CrossRef]
23. Chahar, B.R.; Graillot, D.; Gaur, S. Storm-water management through infiltration trenches. *J. Irrig. Drain. Eng.* **2012**, *138*, 274–281. [CrossRef]
24. Gradeci, K.; Labonnote, N.; Sivertsen, E.; Time, B. The use of insurance data in the analysis of Surface Water Flood events—A systematic review. *J. Hydrol.* **2019**, *568*, 194–206. [CrossRef]
25. Janicka, E.; Kanclerz, J. Assessing the Effects of Urbanization on Water Flow and Flood Events Using the HEC-HMS Model in the Wirynka River Catchment, Poland. *Water* **2022**, *15*, 86. [CrossRef]
26. Hassan, B.T.; Yassine, M.; Amin, D. Comparison of urbanization, climate change, and drainage design impacts on urban flashfloods in an arid region: Case study, New Cairo, Egypt. *Water* **2022**, *14*, 2430. [CrossRef]
27. Wang, J.; Zhang, K.; Yang, M.; Meng, H.; Li, P. The effect of roughness and rainfall on hydrodynamic properties of overland flow. *Hydrol. Res.* **2019**, *50*, 1324–1343. [CrossRef]
28. Wang, X.; Zhang, X. Preparation and Component Optimization of Resin-Based Permeable Brick. *Materials* **2020**, *13*, 2701. [CrossRef]
29. Fu, G.; Zhang, C.; Hall, J.W.; Butler, D. Are sponge cities the solution to China's growing urban flooding problems? *WIREs Water* **2023**, *10*, e1613. [CrossRef]
30. Cheng, T.; Huang, B.; Yang, Z.; Qiu, J.; Zhao, B.; Xu, Z. On the effects of flood reduction for green and grey sponge city measures and their synergistic relationship—Case study in Jinan sponge city pilot area. *Urban Clim.* **2022**, *42*, 101058. [CrossRef]
31. Larsen, T.A.; Hoffmann, S.; Lüthi, C.; Truffer, B.; Maurer, M. Emerging solutions to the water challenges of an urbanizing world. *Science* **2016**, *352*, 928–933. [CrossRef]
32. Bai, S.; Tu, Y.; Sun, H.; Zhang, H.; Yang, S.; Ren, N.-Q. Optimization of wastewater treatment strategies using life cycle assessment from a watershed perspective. *J. Clean. Prod.* **2021**, *312*, 127784. [CrossRef]

33. Ma, J.; Liu, D.; Wang, Z. Sponge City Construction and Urban Economic Sustainable Development: An Ecological Philosophical Perspective. *Int. J. Environ. Res. Public Health* **2023**, *20*, 1694. [CrossRef] [PubMed]
34. Sambito, M.; Freni, G. Strategies for improving optimal positioning of quality sensors in urban drainage systems for non-conservative contaminants. *Water* **2021**, *13*, 934. [CrossRef]
35. Liu, X.; Zhang, Y. Landscape Analysis of Runoff and Sedimentation Based on Land Use/Cover Change in Two Typical Watersheds on the Loess Plateau, China. *Life* **2022**, *12*, 1688. [CrossRef] [PubMed]
36. Zheng, Z.; Duan, X.; Lu, S. The application research of rainwater wetland based on the Sponge City. *Sci. Total Environ.* **2021**, *771*, 144475. [CrossRef] [PubMed]
37. Bai, S.; Chen, J.; Guo, M.; Ren, N.; Zhao, X. Vertical-scale spatial influence of radial oxygen loss on rhizosphere microbial community in constructed wetland. *Environ. Int.* **2023**, *171*, 107690. [CrossRef] [PubMed]
38. Alharbi, T. A Weighted Overlay Analysis for Assessing Urban Flood Risks in Arid Lands: A Case Study of Riyadh, Saudi Arabia. *Water* **2024**, *16*, 397. [CrossRef]
39. Moniruzzaman, M.; Thakur, P.K.; Kumar, P.; Ashraful Alam, M.; Garg, V.; Rousta, I.; Olafsson, H. Decadal urban land use/land cover changes and its impact on surface runoff potential for the Dhaka City and surroundings using remote sensing. *Remote Sens.* **2020**, *13*, 83. [CrossRef]
40. Wang, Q.; Zhao, G.; Zhao, R. Resilient urban expansion: Identifying critical conflict patches by integrating flood risk and land use predictions: A case study of Min Delta Urban Agglomerations in China. *Int. J. Disaster Risk Reduct.* **2024**, *100*, 104192. [CrossRef]
41. Nasar-u-Minallah, M.; Zia, S.; Rahman, A.-U.; Riaz, O. Spatio-Temporal Analysis of Urban Expansion and Future Growth Patterns of Lahore, Pakistan. *Geogr. Environ. Sustain.* **2021**, *14*, 41–53. [CrossRef]
42. Yunping, Z.; Jianping, L.; Yimin, H.; Zebin, C.; Chenhui, Z.; Hao, Y. Delineation of urban growth boundary based on FLUS model under the perspective of land use evaluation in hilly mountainous areas. *J. Mt. Sci.* **2024**, *21*, 1647–1662.
43. Zhao, H.; Gu, T.; Tang, J.; Gong, Z.; Zhao, P. Urban flood risk differentiation under land use scenario simulation. *iScience* **2023**, *26*, 106479. [CrossRef] [PubMed]
44. Lin, J.; He, P.; Yang, L.; He, X.; Lu, S.; Liu, D. Predicting future urban waterlogging-prone areas by coupling the maximum entropy and FLUS model. *Sustain. Cities Soc.* **2022**, *80*, 103812. [CrossRef]
45. Zhang, Z.; Han, L.; Feng, Z.; Zhou, J.; Wang, S.; Wang, X.; Fan, J. Estimating the past and future trajectory of LUCC on wetland ecosystem service values in the Yellow River Delta Region of China. *Sustainability* **2024**, *16*, 619. [CrossRef]
46. Li, W.; Chen, X.; Zheng, J.; Zhang, F.; Yan, Y.; Hai, W.; Han, C.; Liu, L. A Multi-Scenario Simulation and Dynamic Assessment of the Ecosystem Service Values in Key Ecological Functional Areas: A Case Study of the Sichuan Province, China. *Land* **2024**, *13*, 468. [CrossRef]
47. Miao, L.; Ju, L.; Sun, S.; Agathokleous, E.; Wang, Q.; Zhu, Z.; Liu, R.; Zou, Y.; Lu, Y.; Liu, Q. Unveiling the dynamics of sequential extreme precipitation-heatwave compounds in China. *Nature* **2024**, *7*, 67. [CrossRef]
48. Ren, D.-F.; Cao, A.-H.; Wang, F. Response and multi-scenario prediction of carbon storage and habitat quality to land use in liaoning Province, China. *Sustainability* **2023**, *15*, 4500. [CrossRef]
49. Liu, X.; He, J.; Yao, Y.; Zhang, J.; Liang, H.; Wang, H.; Hong, Y. Classifying urban land use by integrating remote sensing and social media data. *Int. J. Geogr. Inf. Sci.* **2017**, *31*, 1675–1696. [CrossRef]
50. Zhao, W.; Wang, J.; Xu, Y.; Chen, S.; Zhang, J.; Tang, S.; Wang, G. Community Resilience Assessment and Identification of Barriers in the Context of Population Aging: A Case Study of Changchun City, China. *Sustainability* **2023**, *15*, 7185. [CrossRef]
51. Zhang, P.; Wu, Y.; Li, C.; Li, R.; Yao, H.; Zhang, Y.; Zhang, G.; Li, D. National-Standards-and Deep-Learning-Oriented Raster and Vector Benchmark Dataset (RVBD) for Land-Use/Land-Cover Mapping in the Yangtze River Basin. *Remote Sens.* **2023**, *15*, 3907. [CrossRef]
52. Shawul, A.A.; Chakma, S. Spatiotemporal detection of land use/land cover change in the large basin using integrated approaches of remote sensing and GIS in the Upper Awash basin, Ethiopia. *Environ. Earth Sci.* **2019**, *78*, 141. [CrossRef]
53. Dong, Q.; Bai, S.; Wang, Z.; Zhao, X.; Yang, S.; Ren, N. Virtual sample generation empowers machine learning-based effluent prediction in constructed wetlands. *J. Environ. Manag.* **2023**, *346*, 118961. [CrossRef] [PubMed]
54. Marin, R.J.; Mattos, Á.J. Physically-based landslide susceptibility analysis using Monte Carlo simulation in a tropical mountain basin. *Georisk* **2020**, *14*, 192–205. [CrossRef]
55. Liu, J.; Yang, J.; Zhang, H. The Control Index for the Construction of Sponge City in the Residential Area: A Case Study of Nanjing Jiangbei New District. *J. Environ. Public Health* **2022**, *2022*, 2209161. [CrossRef] [PubMed]