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Effective Evaluation of Infiltration and Storage Measures in Sponge City Construction: A Case Study of Fenghuang City

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Abstract: In recent years, urban waterlogging problems have become more and more serious, which has led to flood disasters in some cities. The Chinese government launched the sponge city pilot construction in 2015 to mitigate the risk of urban flooding and control the runoff in source areas. Rain-runoff control is one of the main indices of a sponge city, thus, evaluating its control effect is essential for sponge city construction. This paper chose Fenghuang city, located in the west of Hunan province, as a case study area to assess the rainwater control effect by using the MIKE FLOOD model. The results showed that: (1) the total annual runoff control rate (TARCR) of sponge city design was a reasonable indicator for daily rainwater control; (2) the goal of Fenghuang Sponge City was close to the 1-year rainfall event; and (3) infiltration and storage measures could reduce but not eliminate urban waterlogging. The capacity of the drainage system should be fundamentally improved to enhance the prevention standards of urban waterlogging.

Keywords: sponge city; control effect; MIKE FLOOD; rainwater runoff; waterlogging

1. Introduction

Under the influence of urbanization and climate change, urban areas have faced serious flood and waterlogging problems in recent years [1,2]. In China, on average 180 cities were flooded every year, and the number of waterlogged cities was 234 in 2013 and 258 in 2016. In response to the growing problem of urban waterlogging, the Chinese government launched the sponge city pilots in January 2015 [3]. The first batch included 16 pilots in 2015 and second batch had 14 pilots in 2016, and distributed in 28 provinces or municipalities directly under the central government [4]. The concept of the sponge city in China was significantly different from the concept put forward by scholars from Australia, which means a migratory population movement [5]. Figure 1 shows the distribution of pilot cities in China.

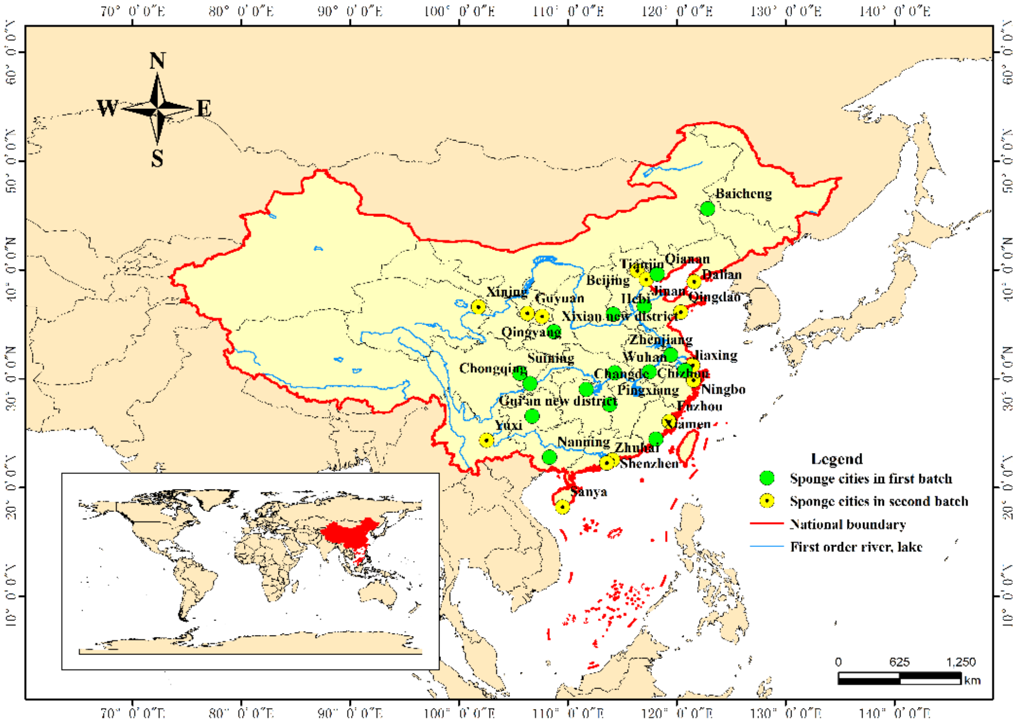


Figure 1. China sponge pilot cities distribution.

A sponge city could be referred to as a "water-resilient city" which means water absorbent, storage, seepage and purification when it rains [6]. According to the "sponge city construction guide" [7], six kinds of low-impact development technologies, such as infiltration, stagnation, storage, purification, use and drainage, are adopted to alleviate city floods [8]. Of them, infiltration, storage, and drainage are closely related to the total runoff control target, which means these measures are effective with urban waterlogging problems [9,10]. Model simulation is necessary to quantitatively evaluate the flood control capability of the sponge city, which is also one of the main methods of the current sponge city planning and design [11].

For the study of urban rain and floods, there are many models, such as the SWMM model [12], the SCS model, the HYDRO model, etc., all models have their own advantages and disadvantages [13]. The MIKE series of hydrodynamics models, developed by the Danish DHI Company, are based on the hydrodynamic equation for discrete solutions [14]. The model can better simulate the one-dimensional river, and two-dimensional and three-dimensional urban environment flooding process under complex environmental conditions [15].

This study is mainly to explore the prevention and control role of a sponge city on urban waterlogging problems, that is, a focus on city rainfall runoff control. Thus, it needs to choose a city which builds a sponge city in whole city area as case study, like Fenghuang City. This paper introduces the process of setting the target of the total annual runoff control rate (TARCR) in Fenghuang Sponge City, and analyzes the expected effect of realizing the construction target by the method of the index decomposition method. This method refers to the design of sponge measures to accomplish the runoff control according to different land-use types. Based on this requirement and combined with the actual information and data, this study chooses MIKE FLOOD to simulate the Fenghuang sponge city rainfall runoff control effect.

2. Study Area and Data

Fenghuang City is located on the western edge of Hunan Province, which is the south-west corner of the Xiangxi Tujia and Miao Autonomous Prefecture, at longitude 109°18′–109°48′, latitude 27°44′–28°19′. The city is a subtropical monsoon humid climate zone, having distinct seasons and a mild climate. The average annual rainfall is 1308.1 mm, the average annual sunshine is 1266.3 h, and the annual average temperature is 15.9 °C.

Figure 2 shows the land-use types and the location of Fenghuang city in Hunan province. The study area is 18.5 km^2, which is shown in the colored area of the map. The blank area is forestland, which is not included in the scope of this study. The study area includes seven types of land use, whose names and area ratios were shown in the legend in Figure 2. There was a river from north-west to south-east through the city, which was Tuo river. The maximum discharge of Tuojiang river without overflowing the river banks in Fenghuang City is 200 m^3/s. The downstream of the river is near Mianzhai town in the south-west. The outlet is marked in Figure 2.

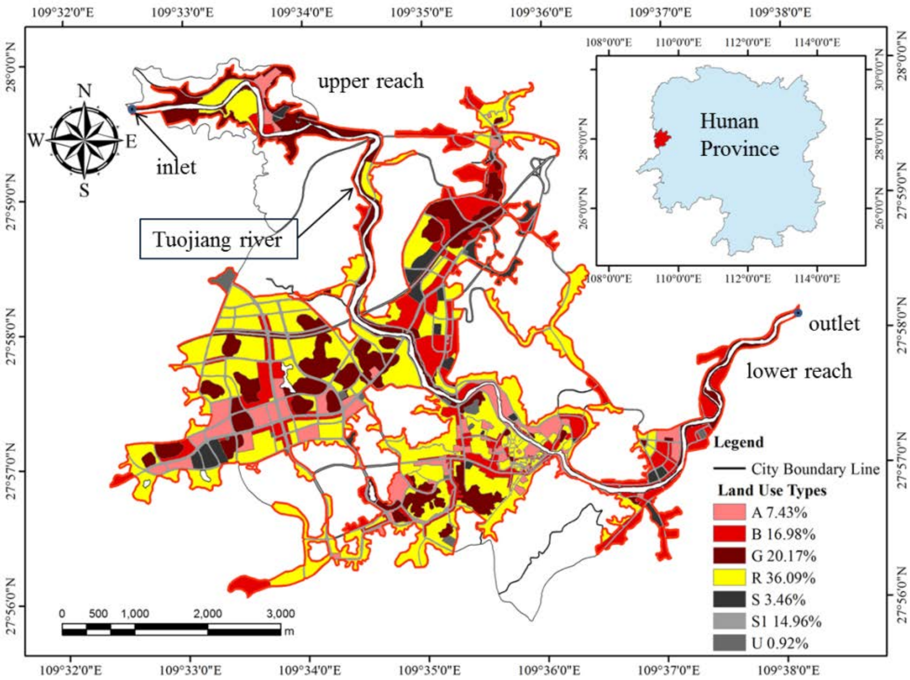


Figure 2. Land-use structure map of Fenghuang City. A: Public management and public service facilities; B: Commercial service facilities; G: Green and square land; R: Residential land; S: Traffic facilities; S1: Urban road land; U: Public facilities land.

Each type of land use includes a different catchment land type, and the rate is determined by the aerial photography. The reference runoff coefficient of different land types is shown in Table 1. The upper limit values of the runoff coefficients were adopted in this study.

Table 1. Reference value of runoff coefficient for different land types.

Catchment Land Type	Runoff Coefficient ϕ
Green roof (matrix thinkness ≥ 300 mm)	0.30–0.40
Hard roof, paved pavement, asphalt roof	0.80–0.90
Concrete or asphalt pavement and plaza	0.80–0.90
Asphalt surface treated gravel pavement and plaza	0.45–0.55
Green land	0.15–0.2
Water surface	1
Permeable pavement	0.08–0.45

3. Methods

3.1. Total Annual Runoff Control Rate (TARCR) Target Setting

According to the "sponge city construction guide", the TARCR is generally used as the control target in the total runoff control of a low impact rain water system [16]. The guide provides statistics and analysis of the daily rainfall in nearly 200 cities in China from 1983 to 2012. The total annual runoff control rate and its corresponding design rainfall value relationship are obtained respectively. Based on the above data analysis, this guide divides the mainland area into five regions, and gives the minimum and maximum values of the TARCR of each region [7]. Fenghuang City is located in the area of the TARCR range (75% ≤ α ≤ 85%) according to the TARCR of the Sponge City Construction Technology Guide issued by the Ministry of Urban and Rural Construction. Considering urban construction, hydrometeorology, topography, and the socio-economic situation of Fenghuang City, the final target rate of the TARCR is 80%.

In order to establish a corresponding relationship between TARCR and daily rainfall, the daily rainfall data of Fenghuang station from 1962 to 2014 was selected and analyzed. In these 53 years, there were 4916 daily rainfall events of greater than 2 mm. The rainfall amount equal to 2 mm was deducted for each rain event as it represents initial losses, meaning that a rainfall amount less than or equal to 2 mm does not lead to runoff. The 4916 effective rainfall rain events are arranged in ascending order. P_i represents the i rainfall value ($1 \leq i \leq 4916$) ordered from small to large magnitudes. For each rainfall event k ($1 \leq k \leq 4916$), whose precipitation is marked as P_k, the value Ψ_k of TARCR is computed based on the following equation:

$$\psi_k = \frac{\sum\limits_{i=1}^{k} P_i + (4916 - k)P_k}{\sum\limits_{i=1}^{4916} P_i} \tag{1}$$

According to the Sponge City Construction Guide, the TARCR is defined as the proportion of annual controlled (not discharged) rainfall to the total annual rainfall. For a certain rainfall, P_k the corresponding TARCR is equal to the total rainfall less than or equal to this value divided by the annual total rainfall. The numerator is, therefore, the sum of 2 terms: the first term is the amount of daily rainfall less than or equal to P_k, while the second term is equal to P_k value multiplied by the number of days when the daily rainfall value is bigger than P_k. The denominator is the sum of all 4916 values of effective precipitation and represents the annual total rainfall.

Equation (1) is used to calculate the TARCR for each rainfall; the corresponding curve for TARCR versus rainfall is represented in Figure 3. From this curve, the corresponding design rainfall value for each TARCR is obtained, e.g., for the target TARCR = 80% the design rainfall value is 24.3 mm.

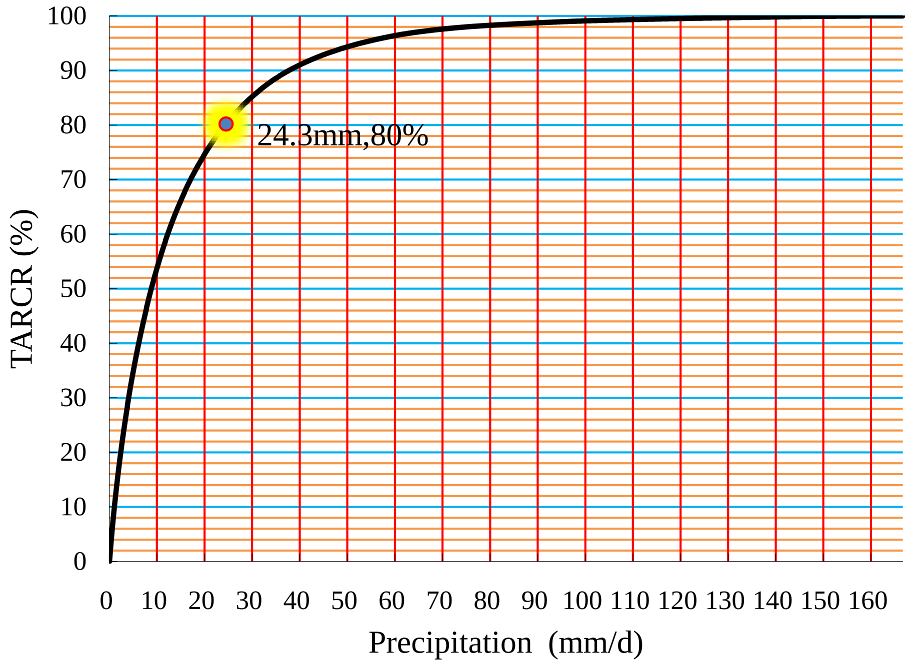


Figure 3. Corresponding relationship curve between the rainfall and total annual runoff control rate (TARCR).

3.2. MIKE FLOOD Simulation

This study used MIKE FLOOD's one-dimensional and two-dimensional coupling function to simulate the dynamic process of a rain and flood disaster in Fenghuang City during heavy rain. The MIKE FLOOD module does not have a separate operating function, but instead calls on the one-dimensional hydrodynamic module (MIKE11 or MIKE Urban) and the two-dimensional module (MIKE21) to simulate the flooding process in the urban area [17]. The result of the operation will be stored in the coupled one-dimensional and two-dimensional modules [18]. The spatial data of the study area are: digital elevation model (DEM), road distribution map, river network diagram and river section data, underground pipe network data, etc., all the spatial data to be unified to the same coordinate system [19]. The main meteorological data were rainfall related data, including rainfall duration, rainfall intensity, etc. The main hydrological data included river discharge, water level, etc. The time step of the data was 1 h [20].

MIKE URBAN integrated ArcGIS, drainage network system and the water supply network to form a set of urban water simulation system. Its hydrodynamic module, MIKE Urban CS, is a model used to study unsteady flow in urban underground pipe networks. The basic principle of the model is the Saint-Venant equation set.

The mass conservation equation is:

$$\frac{\partial Q}{\partial x} = \frac{\partial A}{\partial t} \tag{2}$$

The momentum conservation equation is:

$$\frac{\partial Q}{\partial t} + \frac{\partial\left(\alpha \frac{Q^2}{A}\right)}{\partial x} + gA\frac{\partial h}{\partial x} + \frac{gQ|Q|}{C^2AR} = 0 \tag{3}$$

where x is distance scale, g is gravity acceleration, t is time scale, A is cross section area, R is hydraulic radius, C is Chézy coefficient, and Q is flow.

The study selected the rainfall data and hydrological data with a time step of 1 h from 1 January 2008 to 12 December 2009 as the simulated data to calibrate the model parameters. The calibration results of the surface-rootzone and ground water parameters in MIKE 11 RR are shown in the Table 2.

Table 2. Model rating parameters.

U_{max}	L_{max}	C_{QOF}	C_{KIF}	$CK_{1,2}$	TOF	TIF	TG	CK_{BF}
12	123	0.342	568.3	24.8	0.416	0.021	0.00663	4274

U_{max} is the maximum water content in surface storage, L_{max} is the maximum water content in root zone storage, C_{QOF} is the overland flow runoff coefficient, C_{KIF} is the time constant for routing interflow, $CK_{1,2}$ is the time constant for routing overland flow, TOF is the root zone threshold value for overland flow, TIF is the root zone threshold value for interflow, TG is the root zone threshold value for GW recharge, and CK_{BF} is the time constant for routing baseflow.

A rainfall on 15 July 2014 was selected for the model validation. It was a severe rainstorm, which lasted for 63 hours and the total rainfall volume was 3.96 million m^3 in the study area. The rainfall process in the hour scale was showed by the histogram of Figure 4. The magnitude of the flood was illustrated by the water level in the river: 4.02 m above the warning level and 2.02 m above the guaranteed level, in which the guaranteed water level was defined as an upper limit of water level to ensure the safe operation of the dikes and their subsidiary works. The depth of water accumulated in the urban area reached 1 m. The simulated volume (the red curve) and the measured value (the blue curve) of the discharge at the outlet are shown in Figure 4. The input flow data at the inlet was the measured values. The Nash–Sutcliffe model efficiency coefficient (EF) and the root-mean-square error (RMSE) value [21] were used to assess the model performance; EF = 0.89 which indicates an almost perfect match of model discharge to the measured data, while RMSE = 29.74. The simulation showed that the simulated runoff fitted very well with measured total amount of rainwater discharge, which proved that the parameters of the model are reasonable and the MIKE URBAN model can be adopted to simulate the runoff process for Fenghuang City.

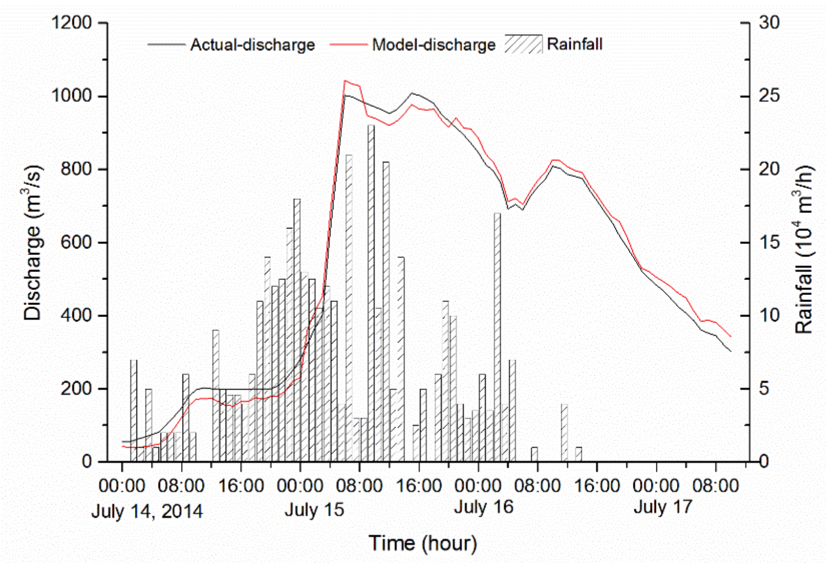
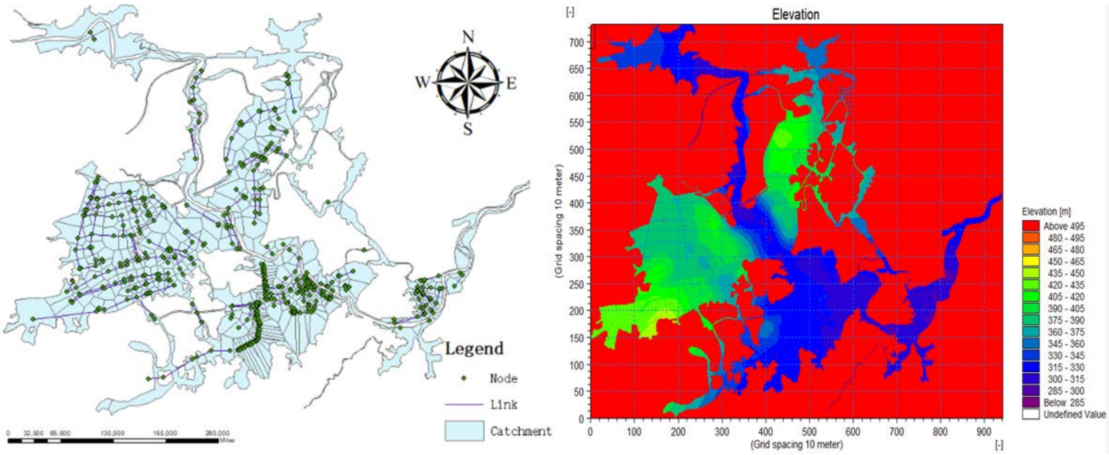


Figure 4. Simulation and measured rainfall flow of Fenghuang City in 15 July 2014.

Figure 5a showed the pipe network and catchments of the study area in MIKE URBAN. The pipe network consisted of 402 nodes and 375 pipes. The total length of the pipe network was 120.3 km and the density of the pipe network was 6.5 km/km^2. There were also 22 outlets in the study area, and the catchment number was 415. The topographic map established by the MIKE 21 model is shown in Figure 5b.



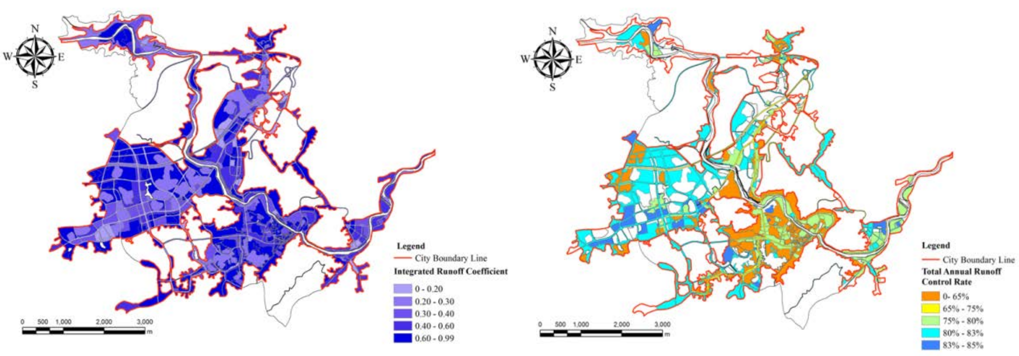
(**a**) (**b**)

Figure 5. Pipe network (**a**) and topographic map (**b**) in MIKE model.

4. Results and Discussion

4.1. Indexes Decomposition Expected Outcome

The runoff coefficient was calculated by the area weighting according to the legend type of each land and the corresponding runoff coefficient (Table 1). Runoff control was mainly determined by the storage volume of depressed green land and water surface. Figure 6 showed the distribution of runoff coefficient (a) and runoff control rate (b). The deep color areas with large runoff coefficient were usually residential land and commercial land, which had a lot of buildings and hardened ground, especially impermeable ground. Correspondingly, the TARCR of these areas was relatively lower than other areas in Figure 6b. The TARCR of the whole city was 80.41% by area weighted calculation of each plot in design rainfall condition. In the index decomposition design, the most important measure of rainfall control was storage, and the total storage volume was 440,000 m^3 in the Fenghuang City area. The daily rainfall depth is 24.3 mm in the sponge city design condition, and the total rainfall volume is 449,500 m^3. The average comprehensive runoff coefficient is 0.51, and the runoff volume under design rainfall is 229,271 m^3. Therefore, the storage volume met the demand of runoff volume in the condition of design rainfall for the TARCR target in Fenghuang City.



(**a**) (**b**)

Figure 6. Expected effect of Fenghuang Sponge City design, (**a**) runoff coefficient; (**b**) TARCR.

4.2. Simulation Results

In order to check the control effect of the daily rainfall in the sponge city design under the condition of satisfying the TARCR, this study simulated the daily rainfall condition of sponge design

(24.3 mm), 1-year (31 mm), 5-year (115 mm), and 10-year (137 mm). Figure 7a,b,c,d showed the rainfall, control (infiltration + storage), drainage, and waterlogging process in 24 h in these four conditions, respectively. It should be noted that the initial interception of rainwater is considered to be the infiltration in this study, so the initial infiltration control rate is 100%.

Figure 7a showed that in the design of rainfall conditions, the proportion of drainage was kept below 20%, which indicated that the rainwater runoff control rate was higher than 80% (met with the sponge city design goal). There was no waterlogging phenomenon in the urban area. From these two indicators, sponge city design was reasonable, and the runoff control objectives could be achieved. According to the information provided by the local planning and design section, the daily rainfall in the 1-year condition was 31 mm, and the rainfall process was calculated by the rainfall pattern in Chicago. The results showed that there was no city waterlogging happened in the 1-year rainfall condition in Figure 7b. The maximum drainage rate was near to the 20% boundary line of the sponge city, and the control rate was close to 80%, which indicated that the sponge city can control 1-year rainfall and avoid the occurrence of waterlogging.

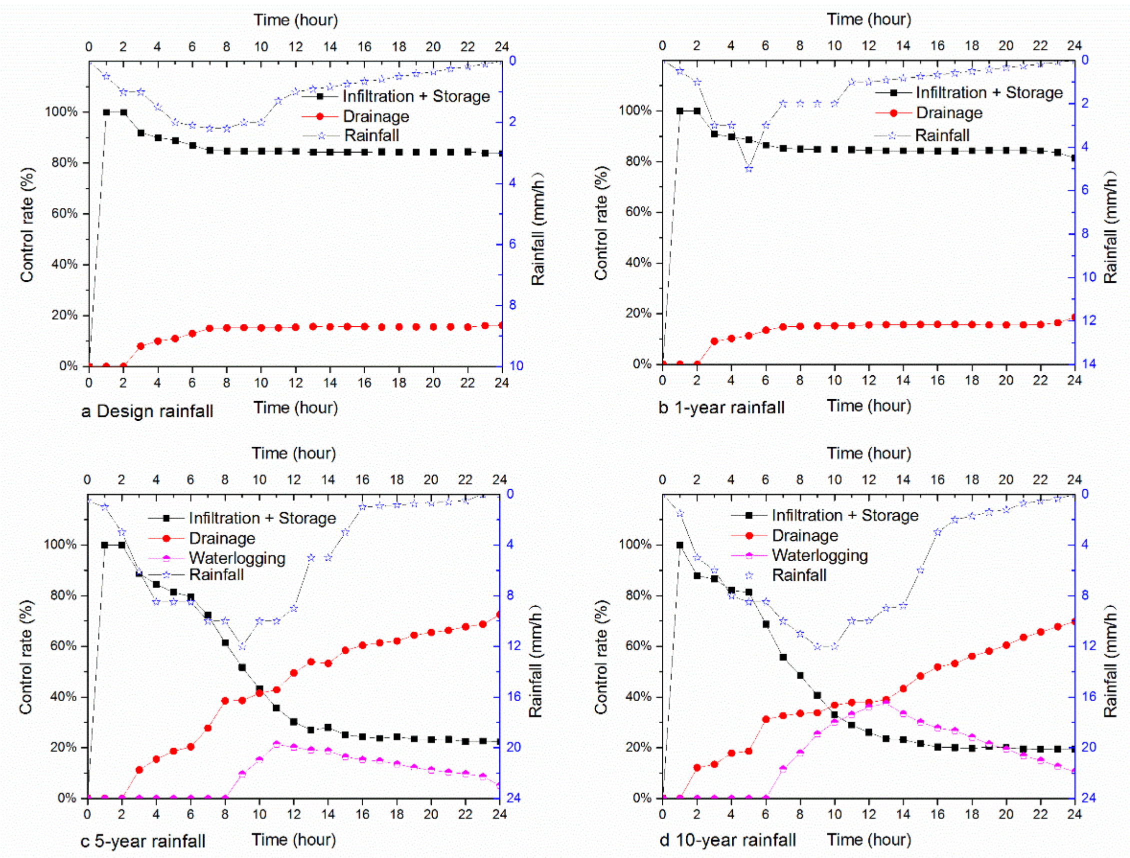


Figure 7. Control, drainage, and waterlogging rate process in design rainfall (**a**), 1-year (**b**), 5-year (**c**), 10-year, (**d**) rainfall condition.

In Figure 7c, there was a pink line, representing the proportion of ground waterlogging in total rainfall. The results show that the waterlogging happened in a 5-year rainfall condition. The waterlogging occurred at about 8 a.m. and the peak rate time was 11 a.m., and the largest amount of waterlogging accounted for 19% of the rainfall volume at this time point; the corresponding average waterlogging depth of water was 18 mm. The sum rate of infiltration and storage decreased rapidly at first until the end of the rainfall, and transferred to stable above the 20% level, which was determined by the limited storage volume and infiltration capability. The drainage rate continuously increased until draining out the runoff and waterlogging water. Figure 7d shows the proportion of control, drainage, and waterlogging of Fenghuang City in a 10-year rain, just like the 5-year condition; the control rate decreased rapidly before reach the rain peak point (9 a.m.) and turned to stable later. The waterlogging began at 6 a.m. and reached a peak at 1 p.m., then declined with the continuously increased drainage rate and volume. The maximum amount of waterlogging accounted for 42% of the rainfall at this time point, and the average waterlogging depth was 47 mm in city.

The results showed that the designed rainfall corresponding to the goal of TARCR of the Fenghuang Sponge City design was less than a 1-year rainfall. The infiltration and storage facilities that were designed in Fenghuang Sponge City could control 1-year rain water and prevent waterlogging. The control rate decreased rapidly in the 5-year and 10-year rainfall conditions and waterlogging happened when the rainfall runoff exceeded the amount of water infiltrated, stored and drained, or when the rainfall intensity was greater than the sum of infiltration, storage and drainage intensity [22]. In the process of sponge city construction, the infiltration and storage space was limited, and usually these volumes were used once in 24 h, which means that the infiltration and storage space was the controlled amount of rainwater in one day [23,24]. In the absence of blockage in the drainage system, drainage was a continuous process; with the infiltration and storage capacity saturated, the remaining runoff could only be discharged through the drainage system. Therefore, the drainage system and its drainage capacity were the key to solving the problem of urban waterlogging [10,15].

5. Conclusions

This study focused on sponge-city controlled rainfall runoff, selected Fenghuang City as the research object, and revealed the design method and expected effect of a sponge-city urban rainfall-runoff control target by the index decomposition method. Based on the MIKE FLOOD model, a simulation was conducted to study the rainfall control flow, displacement and surface waterlogging under the conditions of design, 1-year, 5-year, and 10-year frequency rainfalls. The following main conclusions are drawn:

In the sponge city design, the goal decomposition method is an effective and reasonable method to solve the problem of rainfall runoff control. The goal of TARCR could be reasonably decomposed into specific plots and meet their actual conditions. The TARCR of indicators was reasonable because the simulated results of the daily rain-runoff process in a design rainfall condition were similar with the index decomposition target. The results showed that the target of TARCR in Fenghuang City could be achieved by the method of index decomposition design, and the simulation result of MIKE FLOOD also proved this result.

The sponge city design of Fenghuang City could control a 1-year rainfall that did not produce waterlogging problems, and reduce the extent of waterlogging in heavy rain conditions, such as 5-year or 10-year rainfalls. Therefore, a sponge city could reduce urban waterlogging, but not eliminate it, and the control effect depends on sponge city infiltration and storage capacity [25]. However, the infiltration and storage capacity of a city is limited, and usually the volume can be used only once in 24 h at a time [26]. In the case of heavy rainfall intensity or rainfall, the rainfall exceeded the control of infiltration and storage, and runoff was discharged through the drainage system. Therefore, it can be concluded that a rational drainage system and drainage capacity was necessary for fundamentally improving urban flood control standards.

Author Contributions: J.Z. and J.L. conceived and designed the research; W.S. participated in the development of this study; K.Z. and Y.W. built the MIKE FLOOD model; Y.Y. and C.M. performed the simulation and analyzed the data; J.Z. wrote the paper. All authors made significant contributions to this research and have approved the final manuscript.

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References

1. Jiang, H.; Jiang, Y.; Zheng, Z.; Zhou, J. Study of integrated design storm in urban waterlogging. *Wat. Resour. Power* **2016**, *34*, 53–56.
2. Sang, Y.F.; Yang, M.Y. Urban waterlogs control in china: More effective strategies and actions are needed. *Nat. Hazards* **2017**, *85*, 1291–1294. [CrossRef]
3. Hu, M.; Zhang, X.; Siu, Y.L.; Li, Y.; Tanaka, K.; Yang, H.; Xu, Y. Flood mitigation by permeable pavements in chinese sponge city construction. *Water* **2018**, *10*, 172. [CrossRef]
4. Li, H.; Ding, L.; Ren, M.; Li, C.; Wang, H. Sponge city construction in china: A survey of the challenges and opportunities. *Water* **2017**, *9*, 594. [CrossRef]
5. Argent, N.; Rolley, F.; Walmsley, J. The sponge city hypothesis: Does it hold water? *Aust. Geogr.* **2008**, *39*, 109–130. [CrossRef]
6. Bao, Y.; Luo, D.; Destech Publicat, I. China's current urban water resource problems and effective strategies of sponge city. In Proceedings of the 2016 International Conference on Energy Development and Environmental Protection, Bejing, China, 11–12 June 2016; pp. 472–476.
7. Ministry of Housing Urban-Rural Construction of the people's Republic of China. *Technical Guide for Sponge City Construction-Construction of Rain Water system for low impact Development*; MOHURD: Beijing, China, 2014; pp. 1–88.
8. Szklarek, S.; Wagner, I.; Jurczak, T.; Zalewski, M. Sequential sedimentation-biofiltration system for the purification of a small urban river (the Sokolowka, Lodz) supplied by stormwater. *J. Environ. Manag.* **2018**, *205*, 201–208. [CrossRef] [PubMed]
9. Jia, H.F.; Wang, Z.; Zhen, X.Y.; Clar, M.; Yu, S.L. China's sponge city construction: A discussion on technical approaches. *Front. Environ. Sci. Eng.* **2017**, *11*, 18. [CrossRef]
10. Liu, D.S. China's sponge cities to soak up rainwater. *Nature* **2016**, *537*, 307. [CrossRef] [PubMed]
11. Luo, Y.; Li, M.H. Building sponge city: Examples of landscape architecture curriculum on stormwater management in the united states. *Landsc. Archit. Front.* **2016**, *4*, 62–77.
12. Chen, X.; Deng, H.P.; Ma, X.X.; He, Y.N. Research on the matched recurrence interval relationship between urban waterlogging control and drainage system based on storm water management model. In Proceedings of the 2nd International Symposium on Aqua Science, Water Resource and Low Carbon Energy, Sanya, China, 7–10 Decembar 2009; Jin, F.M., Zhou, Q., Wu, B., Xie, L., Eds.; American Institute of Physics: Melville, NY, USA, 2010; Volume 1251, pp. 141–144.
13. Andrew, R.F. Spatial evaluation of multiple benefits to encourage multi-functional design of sustainable drainage in blue-green cities. *Water* **2017**, *9*, 953. [CrossRef]
14. Locatelli, L.; Gabriel, S.; Mark, O.; Mikkelsen, P.S.; Arnbjerg-Nielsen, K.; Taylor, H.; Bockhorn, B.; Larsen, H.; Kjolby, M.J.; Blicher, A.S.; et al. Modelling the impact of retention-detention units on sewer surcharge and peak and annual runoff reduction. *Wat. Sci. Technol.* **2015**, *71*, 898–903. [CrossRef] [PubMed]
15. Bisht, D.S.; Chatterjee, C.; Kalakoti, S.; Upadhyay, P.; Sahoo, M.; Panda, A. Modeling urban floods and drainage using swmm and mike urban: A case study. *Nat. Hazards* **2016**, *84*, 749–776. [CrossRef]
16. Wang, H.; Mei, C.; Liu, J.H.; Shao, W.W. A new strategy for integrated urban water management in China: Sponge city. *Sci. China Technol. Sci.* **2018**, *61*, 317–329. [CrossRef]
17. Li, C.Q.; Wang, W. Urban flood modeling using 1d-2d coupled hydraulic models. *Disaster Adv.* **2012**, *5*, 1086–1090.
18. Li, C.Q.; Jia, C.; Xu, B.S. Development of a decision support system for flood warning in jinan city. In *Advanced Research on Information Science, Automation and Material System*; Zhang, H., Shen, G., Jin, D., Eds.; Scientific.Net: Zürich, Switzerland, 2011; Volume 219–220, pp. 1267–1270. [CrossRef]
19. Jiang, X.Y.; Ji, Y.; Zhang, J.Q.; Tong, Z.J.; Bao, Y.L.; Chen, P.; Jiang, L.P. The simulation on hazard of urban waterlogging disaster based on gis. In *Chinese Perspective on Risk Analysis and Crisis Response*; Huang, C.F., Zhang, J.Q., Zhou, Z.F., Eds.; Atlantis Press: Paris, France, 2010; Volume 13, p. 280.

20. Holden, J.; Howard, A.J.; West, L.J.; Maxfield, E.; Panter, I.; Oxley, J. A critical review of hydrological data collection for assessing preservation risk for urban waterlogged archaeology: A case study from the City of York, UK. *J. Environ. Manag.* **2009**, *90*, 3197–3204. [CrossRef] [PubMed]
21. Walega, A.; Cupak, A.; Amatya, D.M.; Drozdzal, E. Comparison of direct outflow calculated by modified scs-cn methods for mountainous and highland catchments in upper vistula basin, poland and lowland catchment in South Carolina, U.S.A. *Acta Sci. Pol.-Form. Circumiectus* **2017**, *16*, 187–207. [CrossRef]
22. Luan, Q.H.; Fu, X.R.; Song, C.P.; Wang, H.C.; Liu, J.H.; Wang, Y. Runoff effect evaluation of lid through swmm in typical mountainous, low-lying urban areas: A case study in china. *Water* **2017**, *9*, 439. [CrossRef]
23. Fu, J.-C.; Jang, J.-H.; Huang, C.-M.; Lin, W.-Y.; Yeh, C.-C. Cross-analysis of land and runoff variations in response to urbanization on basin, watershed, and city scales with/without green infrastructures. *Water* **2018**, *10*, 106. [CrossRef]
24. Lyu, H.-M.; Wang, G.-F.; Shen, J.S.; Lu, L.-H.; Wang, G.-Q. Analysis and gis mapping of flooding hazards on 10 May 2016, Guangzhou, China. *Water* **2016**, *8*, 447. [CrossRef]
25. Li, X.N.; Li, J.Q.; Fang, X.; Gong, Y.W.; Wang, W.L. Case studies of the sponge city program in china. In Proceedings of the World Environmental and Water Resources Congress 2016: Watershed Management, Irrigation and Drainage, and Water Resources Planning and Management, West Palm Beach, FL, USA, 22–26 May 2016; pp. 295–308.
26. Hlodversdottir, A.O.; Bjornsson, B.; Andradottir, H.O.; Eliasson, J.; Crochet, P. Assessment of flood hazard in a combined sewer system in reykjavik city centre. *Water Sci. Technol.* **2015**, *71*, 1471–1477. [CrossRef] [PubMed]