Effect of urban underlying surface change on stormwater runoff process based on the SWMM and Green-Ampt infiltration model

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ABSTRACT

The acceleration of urbanization has brought significant changes to the urban underlying surface. As a result, the flood disaster caused by stormwater runoff has become increasingly prominent. The infiltration function of the permeable area can lead to flood disasters, but the extent and depth of the effect are still unclear. Therefore, based on the storm water management model (SWMM) and Green-Ampt infiltration model, this paper discussed the effect of improving soil saturated hydraulic conductivity (SSHC) and soil capillary suction head (SCSH) on the stormwater runoff process. The results show that the increase of SSHC and SCSH can significantly reduce runoff and increase infiltration. However, the improvement of SSHC can more effectively alleviate flood disasters compared with the improvement of SCSH. And the change of SSHC has a significant effect on the stormwater runoff with a critical SSHC value while the effect can be ignored. In addition, there is a cross value; when the value of SSHC and SCSH is larger than the cross value, the difference between SSHC and SCSH in reducing runoff duration no longer exists. The critical value and cross value are not constant but change with the change of rainfall intensity.

Key words: impervious rate, rainfall intensity, soil capillary suction head, soil saturated hydraulic conductivity, stormwater runoff, urban underlying surface

HIGHLIGHTS

- The effect of an urban underlying surface change on stormwater runoff is notionally studied.
- Improving SSHC can reduce total runoff and increase total infiltration more effectively than improving SCSH.
- There is an effect of rainfall intensity and urban IR in SSHC and SCSH on soil infiltration.
- There exists a critical SSHC value, below which the change of SSHC has a significant effect on the stormwater runoff.

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INTRODUCTION

With the rapid economic development and population increase, the urbanization process is accelerating (Zhang et al. 2018). According to the United Nations world urbanization prospects: the 2018 revision, the number of urban residents in various countries rose from 751 million in 1950 to 4.2 billion in 2018. By 2050, 68% of the world’s population will live in urban areas (UN 2018). In China, the urbanization rate of the resident population will exceed 60% for the first time in 2019 (Li 2020). By 2025, China’s urbanization rate will reach 65.5%, with an additional 80 million urban population (CRDG 2020). Before 2050, China’s urbanization rate may reach over 70% (Zhu et al. 2011). Therefore, as the essential habitat for human beings, the environmental problems in the urban areas have attracted more public attention (Gao et al. 2013).

After the entrance of the 21st century, most of the cities in all countries have suffered from severe rainstorms and floods (Rogger et al. 2017). Urban rainfall duration is short, rainfall intensity is large (Wang et al. 2009), and flood frequency is high (Stedinger & Griffis 2011), which increases the pressure of urban drainage system (Zevenbergen et al. 2008) and the risk of urban rainstorms and floods (Bernice et al. 2019). Urban waterlogging not only dramatically affects urban traffic but also damages urban public infrastructure and threatens people’s life and property safety (Darabi et al. 2019). For example, on July 21, 2012, the cumulative rainfall in 18 hours in Beijing exceeded 460 mm, causing more than 1.9 million people to be affected, and 79 people died, and the economic loss amounted to nearly 11.64 billion (Zhang et al. 2013). Similarly, in cities such as Shanghai and Guangzhou, China (Shi & Cui 2012; Lyu et al. 2016), Wales, UK (Pregnolato et al. 2017), Louisiana, USA (Wang et al. 2019),...
among others, are all heavily affected by urban flooding. Rose et al. (2008) showed that rainfall frequency in urbanised areas increased significantly compared with other areas. The rainfall in urbanized areas is 12–14% higher than that in other areas, and the rainfall in urban centers is 6% higher than that in suburban areas (Shepherd et al. 2002). Increasingly frequent rainstorms and floods disasters are closely related to the changes in land-use patterns on the underlying surface caused by human activities (Sherrard & Jacobs 2012). Urbanization is a significant manifestation of social changes on the underlying natural surface (Pielke 2005).

Because of the harmfulness and frequency of urban floods, stormwater runoff management has become the focus of flood research. With the development of computer technology and numerical calculation technology, the numerical model has become an essential means to study urban flood problems (Semadeni-Davies et al. 2008). The way to predict the impact of stormwater runoff on the urban is of great significance to managing urban water resources. The stormwater runoff model has been widely applied (Kanso et al. 2006). The stormwater management model (SWMM) is a software developed by the U.S. Environmental Protection Agency (EPA) to simulate the hydro-logical processes related to rainfall and runoff in urban areas. The SWMM has become the first choice of domestic and foreign scholars due to its advantages such as open-source code, stable operation, clear principle, flexible and practical application (Zhu et al. 2019), and powerful functions (Wijesiri et al. 2016). SWMM has been widely used in the simulation, analysis, and design of urban storm runoff, drainage pipeline system, watershed planning, etc. all over the world (Peterson & Wicks 2006), and gradually applied in non-urban areas (Jennifer 2008), with strong practicability (Lowe 2010). It has been used in South Korea (Kim et al. 2014), the United States (Tsirhintzis et al. 2015), Finland (Tuomela et al. 2019), etc., and achieved good effect.

The rapid urbanization process has turned the underlying surface of the original natural river basin into various building facilities such as streets, squares, and parks (Zou et al. 2007). As an essential carrier of the surface hydro-logical process, the underlying urban surface is highly spatial-variability, which leads to the complexity of the urban hydro-logical process (Rossel et al. 2014). The importance of land use/land cover change makes it a hot and core issue in global environmental change research (Torbick et al. 2006). Among the influencing factors of urban rainfall and flood, land cover is the main factor, which is also the content of current researches (Li & Wang 2009). As an essential previous layer in the urban center, the green space zone has been widely concerned for its role in reducing urban stormwater runoff, reducing peak runoff, and restraining flood (Zhang et al. 2015). Yang et al. (2015) also found that urban green space effectively reduces the velocity and peak runoff by increasing infiltration rate and surface roughness in the Onondaga Creek watershed in New York, USA. In 2009, the regulation and storage of stormwater runoff by green space zone in Beijing reached 1.54 m³, and the regulation and storage of rainwater runoff per unit area of green space zone were 2,494 m³/ha (Zhang et al. 2012). Thus, there are urban permeable areas (e.g., green space zone) that have a favorable effect on the infiltration of rainwater in urban, but the extent and depth of the effect of permeable areas are still unclear. The primary purpose of this paper is to explain the effect of the infiltration capacity of permeable areas on stormwater runoff to provide a theoretical basis for improving the infiltration capacity of permeable areas to control urban flood disasters effectively. In this study, the SWMM and Green-Ampt infiltration models were used to investigate the effects of SCSH and SSHC at different levels under three cases. This paper also discusses the effects of rainfall intensity and urban impervious rate and the limitations. In a nutshell, this paper provides new insight into people’s understanding of urban flood disaster mechanisms and the awareness of using urban permeable zones.

MATERIALS AND METHODS

Study model

SWMM generally includes a stormwater runoff sub-module, surface concentration sub-module, and flow operator sub-module (Adams & Papa 2001). In addition, SWMM realizes a variety of functions through meteorological elements, surface elements, aquifer elements and transfer elements (Rossman 2015). Figure 1(a) is the conceptual model of SWMM. This paper’s purpose and the SWMM conceptual model established the simplest SWMM model (Figure 1(b)), which contains one sub-catchment, one rain gage, one junction one, conduit, and one outfall. The values of SWMM model parameters (Table 1) mainly refer to the SWMM user manual (Rodriguez et al. 2008; Rossman 2015).
This paper adopts the surface yield flow to calculate using the nonlinear reservoir method, and the equations were solved through the simultaneous continuity equation and manning equation to obtain the surface yield flow (Rossman 2015).

\[ Q = \frac{w}{n} \frac{1.49}{4S} (d - d_s)^2 S \]  (1)

where \( Q \) is runoff quality (m\(^3\)/s); \( w \) is the width of overland flow path; \( d \) is depth; \( d_s \) is maximum depression water storage depth; \( S \) is the average surface slope.

SWMM has three basic infiltration models, namely, the Horton model (Horton 1933), the Green-Ampt model (Bouwer 1976), and the SCS curve number model (Bisht et al. 2016). As the Green-Ampt model has vital physical significance, few parameters, simple solutions, and other advantages, it widely uses in the study of infiltration (Mohammadzadeh-habili & Heidarpour 2015; Ali et al. 2016). Accordingly, the Green-Ampt model can be expressed as the following equation.
(a) If \( F < F_s, f < i \)
\[
i > K_s \quad F_s = \frac{S \cdot \text{IMD}}{i/K_s - 1} \tag{2}
\]
\[
i \leq K_s \quad F_s = 0 \tag{3}
\]
(b) If \( F \geq F_s \)
\[
f = f_p \quad f_p = K_s \left(1 + \frac{S \cdot \text{IMD}}{F}\right) \tag{4}
\]
where \( f \) is the infiltration rate, \( \text{mm/s} \); \( f_p \) is the stable infiltration rate, \( \text{mm/s} \); \( F \) is the cumulative infiltration, \( \text{mm} \); \( F_s \) is the cumulative infiltration to saturate the soil, \( \text{mm} \); \( S \) is the average capillary suction at the wet front, \( \text{mm} \); \( i \) is the rainfall intensity, \( \text{mm/s} \); \( K_s \) is the soil hydraulic conductivity, \( \text{mm/s} \); \( \text{IMD} \) is the wet deficit value, \( \text{mm/mm} \).

Design rainfall event

The rainfall intensity, air temperature, and wind in meteorological factors all have a particular effect on infiltration but mainly show the effect of rainfall intensity on infiltration. From the mechanics perspective, infiltration is closely related to rainfall kinetic energy, closely related to rainfall intensity. Therefore, rainfall intensity is also an essential factor affecting infiltration performance (Qi et al. 2010). This paper adopts the calculation formula of rainstorm intensity in Dongguan, Guangzhou, China (Equation (5)). The designed rainfall event is a storm with a rainfall duration of 3 hours and a return period of 1 year.

\[
q = \frac{3717.342 \times (1 + 0.503 \log p)}{(t + 14.533)^{1.28}} \tag{5}
\]
where \( q \) (L/(s·ha)) is the average rainfall unit yield in \( t \) time; \( p \) (year) is the return period; \( t \) (min) is the duration of rainfall.

The Chicago storm profile (Keifer & Chu 1957) uses to generate rainfall time series data. The rainstorm duration was 180 minutes, and the time step was 1 minute. The rain peak coefficient \( R \) is a crucial parameter to control the occurrence time of the rain peak. The smaller the rain peak coefficient is, the earlier the rain peak appears. In China, the precipitation peak coefficient is usually between 0.35 and 0.45 (Guoping et al. 1998). Therefore, this paper sets the peak rainfall coefficient of 0.4 and uses the Chicago storm profile to get the rainfall event with a return period of 1 year, as shown in Figure 2(a).

Figure 2 | Simulated rainfall events with a different return period.
Design simulation scenarios

Soil hydraulic parameters can affect soil infiltration capacity (Zhai et al. 2017). In the Green-Ampt infiltration model, the SSHC and SCSH are the main variables affected by soil structure and texture (Cai et al. 2014). Referring to the SWMM handbook (Lewis 2015; Rossman 2015), Table 2 shows some actual SCSH and SSHC. Since the paper’s research area is a hypothetical area rather than a specific actual urban area, the SCSH range is 50–350 mm, and the SSHC range is 10–110 mm/h. Therefore, this study presents three scenarios.

Scenario 1: this paper considered three different groups of SSHC and SCSH. Each case had ten SSHC and SCSH, combined with one control group, as shown in Table 3. The other parameters in the SWMM remain unchanged.

Scenario 2: in addition to the rainfall intensity of \( P = 1 \)-year in the infiltration capacity scenario, the rainfall events with a return period of \( P = 5 \)-year, \( P = 10 \)-year, \( P = 20 \)-year, \( P = 50 \)-year are also concerned, as shown in Figure 2(b).

Scenario 3: urbanization greatly increases the IR in urban and significantly changes the original natural hydrological and ecological processes, leading to a series of urban stormwater problems (McGrane 2016; Alaoui et al. 2018). Therefore, this paper studied the effect of urban IR on soil infiltration change. The urban IR is 20–90% in

| Soil Texture Class          | Soil saturated hydraulic conductivity (mm/hr) | Soil capillary suction head (mm) |
|-----------------------------|---------------------------------------------|---------------------------------|
| Sand                        | 120.4                                       | 49.0                            |
| Loamy Sand                  | 30.0                                        | 61.0                            |
| Sandy Loam                  | 10.9                                        | 110.0                           |
| Loam                        | 3.3                                         | 169.9                           |
| Silt Loam                   | 1.5                                         | 220.0                           |
| Sandy Clay Loam             | 1.0                                         | 240.0                           |
| Clay Loam                   | 0.5                                         | 301.0                           |
| Silty Clay Loam             | 0.3                                         | 290.1                           |
| Sandy Clay                  | 0.3                                         | 320.0                           |
| Clay                        | 0.5                                         | 270.0                           |
| This study                  | 10–110                                      | 50–350                          |

| Control group | SCSH/SSHC 50/10     | SCSH/SSHC 50/20     | SCSH/SSHC 50/30     |
|---------------|---------------------|---------------------|---------------------|
| Level 1       | SCSH/SSHC 80/10     | SCSH/SSHC 50/20     | SCSH/SSHC 80/20     |
| Level 2       | SCSH/SSHC 110/10    | SCSH/SSHC 50/30     | SCSH/SSHC 110/50    |
| Level 3       | SCSH/SSHC 140/10    | SCSH/SSHC 50/40     | SCSH/SSHC 140/40    |
| Level 4       | SCSH/SSHC 170/10    | SCSH/SSHC 50/50     | SCSH/SSHC 170/50    |
| Level 5       | SCSH/SSHC 200/10    | SCSH/SSHC 50/60     | SCSH/SSHC 200/60    |
| Level 6       | SCSH/SSHC 230/10    | SCSH/SSHC 50/70     | SCSH/SSHC 230/70    |
| Level 7       | SCSH/SSHC 260/10    | SCSH/SSHC 50/80     | SCSH/SSHC 260/80    |
| Level 8       | SCSH/SSHC 290/10    | SCSH/SSHC 50/90     | SCSH/SSHC 290/90    |
| Level 9       | SCSH/SSHC 320/10    | SCSH/SSHC 50/100    | SCSH/SSHC 320/100   |
| Level 10      | SCSH/SSHC 350/10    | SCSH/SSHC 50/110    | SCSH/SSHC 350/110   |
practice (Tsihintzis & Hamid 2015; Ren et al. 2020). Therefore, this paper considers that IR is 20, 50, 70, and 90%, with other parameters unchanged in SWMM.

RESULT

Scenario1: infiltration capacity change

Figure 3(a) shows total infiltration and total runoff under all three cases. It found that for all three cases, with the increase of SCSH and SSCH, total infiltration (total runoff) gradually increases (decreases). However, we found that total infiltration (total runoff) of case 2 and case 3 is always greater than (less than) case 1, and their increasing (decreasing) rates are different; that is, the slopes of the curves are different. In case 1, the curve slope is almost a constant value; however, in case 2 and case 3, there is a critical SSHC value. The slope decreases gradually below the critical value but becomes 0 above the critical value. The critical SSHC value is 60 mm/hr (Figure 4(a) (L5)) in this simulation. When less than the critical value, total infiltration (total runoff) finally increased (decreased) by 16.97% (24.02%) (Case 1), 37.03% (52.36%) (Case 2), and 37.19% (52.56%) (Case 3), compared with the CG. More significant than the critical value, total infiltration and total runoff of case 2 and case 3 unchanged; in case 1, the increased infiltration rate is 7.55%, and the total runoff decrease is 16.40%. However, the total infiltration (total runoff) of case 1 is still greater than (less than) the values of case 2 and case 3. These observations indicate that increased soil infiltration capacity has a positive impact on reducing total runoff. However, the variation effect of case 1 was not as good as that of case 2 and case 3, which showed that improving SSHC or overall infiltration capacity could reduce urban flooding more effectively than improving soil SCSH. However, the mitigation effects resulting from improved SSHC are not always significant and influential.

Figure 3 | The variation of total infiltration and total runoff (a) and peak runoff (b) in the studied area.

Figure 4 | Runoff duration at different levels. (a) Runoff duration; (b) Difference of runoff duration.
There is a critical value of SSHC, below which soil infiltration has a significant effect on the change of urban stormwater runoff, while above this value, the effect is almost negligible.

Figure 3(b) shows the variation of peak runoff in all three cases. In any case, peak runoff decreases with the increase of soil infiltration rate. Nevertheless, case 1 shows a linear downward trend (slope remains unchanged), while case 2 and case 3 show a gradual downward trend. When the slope is less than L5, it gradually decreases; when it is more significant than L5, the slope is 0, that is, L5 (Figure 3(b) (L5)) is the critical value of peak runoff. Noticeably, the curve of case 2 is always lower than that of case 1 at the same level. In this way, the peak runoff of case 1 is greater than that of case 2. It means that the peak runoff is more sensitive to SSHC than SCSH. In other words, improving SSHC is more effective in reducing peak runoff than reducing SCSH.

Urban flood disaster is related to the peak runoff but related to the runoff duration. Figure 4(a) shows the runoff duration at different SSHC and SCSH. It is seen that the runoff duration of case 1 decreases gradually, and that of case 2 and case 3 decreases from CG to L1 and then remains unchanged, that is, a critical value of runoff duration at L1. When SSHC is increased beyond this value, the runoff duration will not change. In all three cases, the runoff duration reached the same at L8. That is, L8 was a cross value. In other words, the difference of the effect of SSHC and SCSH on runoff duration no longer exists after exceeding L8. Figure 4(b) shows that the runoff duration difference between all cases and CG. The runoff duration of case 2 and case 3 is shorter than that of case 1. Thus, runoff duration indirectly reflects the soil infiltration capacity. Besides, it is worth noting that there is no significant time difference between case 2 and case 3. From this observation, the sensitivity of SSHC to runoff duration is much greater than that of SCSH, but there is a cross value. After the value is exceeded, the difference in the impact of SSHC and SCSH on runoff duration no longer exists.

Scenario 2: rainfall intensity change

Figure 5 shows the effect of rainfall intensity on total runoff and total infiltration. With the increase of rainfall intensity, total runoff and total infiltration gradually increase. The above critical SSHC value can observe when the rainfall intensity is low but seems to disappear when the rainfall intensity is high enough. Besides, the decrease of total runoff and total infiltration rate of increase is different under the different cases for different rainfall intensity. Comparing with runoff depth (total infiltration) of CG from \( P = 1 \)-year to \( P = 50 \)-year, for case 1, total runoff (total infiltration) of level 10 decreased (increased) by 36% (26%), 29% (31%), 26% (33%), 24% (33%), 23% (34%) and 21% (34%), respectively; for case 2, the decreased (increased) by 53% (37%), 62% (66%), 64% (79%), 66% (92%), 66% (99%) and 67% (107%), respectively; for case 3, the decreased (increased) by 53% (37%), 62% (66%), 64% (79%), 66% (92%), 67% (100%) and 68% (109%), respectively. Both case 2 and case 3 total runoff (total infiltration) decrease (increase) much more than case 1. Regardless of rainfall intensity, the improvement of SSHC is more effective than the improvement of SCSH to reduce total runoff and increase total infiltration. If we carefully observe, the total runoff decrease of case 2 and case 3 increases with the increase of rainfall intensity, but the increased amplitude decreases. However, the total infiltration of case 2 and case 3 increases with the increase of rainfall intensity. It means that when the rainfall intensity reaches or exceeds a

![Figure 5](http://iwaponline.com/ws/article-pdf/doi/10.2166/ws.2021.178/896142/ws2021178.pdf)
certain value, the effect of improving SSHC on total runoff reduction may not always be effective, but it is always effective to increase total infiltration.

Figure 6(a) shows the effect of rainfall intensity on peak runoff. The average attenuation of the peak runoff of case 2 and case 3 is about 13–19% and 13–30%, respectively, more massive than 10–13% of case 1. For the critical value of peak runoff, when the rainfall intensity is low, the above critical value SSHC can be found, but when the rainfall intensity is high enough, it seems to disappear. The effect of rainfall intensity on peak runoff decrement is shown in Figure 6(b). When \( P = 1 \)-year and \( P = 5 \)-year, the decrement of peak runoff in case 1 increases, and when it exceeds \( P = 5 \)-year, the decrement of peak runoff unchanged. For case 2 and case 3, peak runoff decrement gradually increases with the increase of rainfall intensity. Therefore, regardless of rainfall intensity, an improvement of SSHC is more effective than an improvement of SCSH in reducing suppressed peak runoff. However, the increase in peak runoff decrement as rainfall intensity increases, which means that improving SSHC may not always be significant in decreasing peak runoff when rainfall intensity reaches or exceeds a particular value.

Figure 7 shows the effect of rainfall intensity on runoff duration. With the increase of rainfall intensity, the runoff duration in case 1 increases continuously, while the runoff duration in case 2 and case 3 decreases sharply. When the rainfall intensity reaches \( L_3 \), the decrease level is between 14.76% and 26.62%. The critical value and cross value of runoff duration change with the increase of rainfall intensity, and larger SSHC and SCSH are needed to reach the critical value and cross value. Therefore, improving SSHC is more effective than improving SCSH to reduce runoff loss time regardless of rainfall intensity. However, with the increase of rainfall intensity, the decline of runoff duration decreases, which means that improving SSHC on reducing peak runoff may not always be practical when rainfall intensity reaches or exceeds a particular value.

Scenario 3: change of urban impervious rate

The effect of urban IR on total infiltration, total runoff, and peak runoff is shown in Figure 8. With the increase of IR, total runoff and peak runoff gradually increase, while total infiltration decreases. In all three cases, total
infiltration (total runoff) decreases (increases) as the IR increases from 20% to 90%. With the increase of IR, the variation range of total infiltration and total runoff becomes smaller and smaller for different cases. For example, for the case of IR of 20%, 50, 70, and 90%, the total runoff difference of case 1 and case 2 at L5 is about 11 mm, 8 mm, 6 mm, and 2 mm, respectively, as shown in Figure 8(a). Besides, when the urban IR reaches 90%, the total infiltration amount of L5 increases from 5 to 7 mm (Case 1), 8 mm (Case 2), and 8 mm (Case 3). However, the average increase of L5 with IR of 20, 50, and 70% was 36.5 mm (IR = 20%), 44.5 mm (IR = 40%), and 54.4 mm (IR = 60%), respectively.
The above findings indicate that SSHC plays an essential role in increasing total runoff and reducing total infiltration when the urban IR is low, but the effect worsens. From Figure 8(c) that with the increase of the urban, the peak runoff also increases in all three cases. However, for different cases, with the increase of IR, the difference of peak runoff variation amplitude between case 1 and case 2 is not as significant as the variation amplitude of total runoff and total infiltration.

Figure 9 shows the effect of the urban IR on different runoff duration. The ordinate value is the difference between CG and runoff duration at each level, Which clearly shows that when the urban IR reaches 70%, peak runoff will not disappear ahead of time regardless of increasing IR. This observation means that with the improvement of urban IR, reducing flood by improving soil properties becomes weaker and weaker. On the contrary, under relatively low urban IR, the effect of IR change, especially SSHC, will be significant.

DISCUSSION

**Antecedent soil water content**

Infiltration is a dynamic process of water distribution in soil. The dynamic infiltration process of water is affected by the initial water content. The initial water content is an essential factor in the process of rainfall infiltration (Li et al. 2015). The initial water content of soil affects the soil's initial permeability, which increases with the increase of the initial water content of soil for the same type of soil (Liu et al. 2011). With the gradual increase of the infiltration time, when the infiltration time is large enough, the effect of initial conditions on the infiltration can be ignored (Philip 1957, 1991). In this paper, the stormwater runoff thoroughly infiltrates, so there is no problem with initial water content.

**Effect of IR on the hydro-logical cycle**

From Figure 8(c), the IR increases from 20% to 80% under different cases, and the increased peak runoff ranges from 219.2% to 253.45%. Other studies also found that if IR increased by 10–100%, the total runoff would
increase by 200–500% (Paul & Meyer 2001). Olivera & Defee (2007) showed that when the urban IR reached 10%, the annual total runoff and peak runoff increased by 146 and 198%. Thus, the increase of the underlying surface impermeability of urban land changes the original urban natural hydro-logical cycle (Xu & Zhao 2016) with the development of the urban, resulting in the decrease of infiltration, an increase in runoff (Carson et al. 2013), and the change of peak runoff (Brath et al. 2006). The final result is a flooding process with ‘high peak runoff and large total runoff’ (Smith et al. 2002), which is a fundamental reason for frequent urban waterlogging (Rosburg et al. 2017; Yazdi et al. 2019). Therefore, the increase in IR will affect the urban hydro-logical cycle.

The impact of SWMM models on the results

The model is the generalization of the real world. The SWMM model adopts the idea of a loose distributed physical model to construct the model, and the model structure error exists in the generalization of the real world. There are strong humanness and uncertainty in digitizing the underlying surface, especially the sub-catchment area. Since the study area in this paper is only 4 ha, it has little effect on the calculation results if divided into smaller sub-catchment. The rainfall data in sub-catchment are calculated based on the formula of rainstorm intensity designed by the rainfall data from the past years, which fails to reflect the spatial gradient of rainfall. However, the study area in this paper is small, and there is no apparent spatial difference.

Limitations and prospects

In this paper, a simple SWMM generalized model containing one sub-catchment was established. Therefore, it is impossible to compare the simulated hydro-logical results or verify the model’s correctness through the actual rainfall events or monitoring data, and further experimental study is needed to determine. Furthermore, although the model parameters determined according to the SWMM manual and the existing literature, the parameters are not verified by monitoring data. Therefore, this paper’s absolute value of the simulated results has no practical significance, but the simulated results’ relative value is credible.

The urban water situation’s simulation area is not only the urban area but also the surrounding suburbs and even can expand. The runoff patterns in these areas may be different from those in urban areas, and the runoff may flow into the river in the form of side inflow. The urban drainage system has both pipe networks, artificial river channels, and natural mountain flood channels, with various section sizes and forms. Land leveling in the process of urbanization has changed the original catchment path. Therefore, the actual effect of permeable areas on the mitigation of urban flood disasters needs further study.

CONCLUSION

This paper focuses on the mechanism and degree of influence of soil infiltration change on urban floods. The theoretical analysis was conducted by use of the SWMM and the Green-Ampt infiltration model. The effect of SSHC and SCSH on the urban runoff process is discussed at different levels under three cases. The most significant observations from the ensuing study can be summarized as follows. Compared with the improvement of SCSH, the improvement of SSHC can alleviate urban stormwater runoff more effectively. There is a critical SSHC value, below which, SSHC change has a significant impact on reducing urban stormwater runoff, while above this value, the impact can ignore. Simultaneously, there is a cross value of SSHC and SCSH in runoff duration, which is larger than the cross value, and the difference between SSHC and SCSH in reducing runoff duration no longer exists. The critical value and cross value change with the change of rainfall intensity. Regardless of rainfall intensity, an improvement of SSHC is more effective than an improvement of SCSH in reducing urban stormwater runoff. However, when rainfall intensity reaches or exceeds a specific value, improving SSHC is not always effective in reducing urban stormwater runoff. The IR has an essential effect on the reduction of runoff by SSHC through changing soil infiltration. When urban IR is low, SSHC plays an essential role in reducing urban stormwater runoff. However, with the increase of IR, the effect becomes worse. And this paper provides new avenues for better understanding the positive effect of urban underlying surface on urban floods.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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