Planning Strategy for the Reduction of Runoff Using Urban Green Space

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Abstract: Urban green space plays an important role in treating stormwater. In a highly dense urban environment, it is difficult to create large areas of green space. To utilize green space in urban areas effectively, locating an effective green space type is important. In this study, we examined the effect of green space on runoff reduction by comparing different green space setting scenarios. By changing the green space area ratio, green space structure, street tree type, and rainfall duration and amount, we compared the runoff rates. The results showed that the green space area ratio was more effective when more than 10% of the area was green space, and the runoff reduction rate was decreased more effectively when the tree canopy LAI (leaf area index) value increased from 2 to 2.5 than when the LAI value was higher. Green space was more effective at lower intensities of rainfall events. Different green space structures cause other effects on evaporation and soil infiltration. Each strategy needs to be implemented correctly for green infrastructure policy purposes.

Keywords: landscape planning; green infrastructure; stormwater treatment; spatial modeling; street tree; LAI

1. Introduction

Rapid urbanization has caused many issues by increasing impervious surfaces [1,2]. Urban floods are an important issue because both their frequency and their intensity and impact have increased recently, since rainfall patterns have changed due to climate change [3,4]. As most infrastructure and populations are located in urban areas [5], urban floods directly impact most of the infrastructure used for urban living, including transportation, electricity, and communication networks [6,7]. To reduce urban floods, traditional stormwater systems use sewer systems that collect stormwater and convey it along with other forms of surface water [8]. Unfortunately, this sewer system in the gray infrastructure only solves the issues of the increasing stormwater runoff that occurs during urban floods [9]. Instead of gray infrastructure, green infrastructure has emerged as a complementary strategy to the gray infrastructure in treating stormwater [10].

Green space in urban areas has a role in balancing the water cycle system, reducing heat, providing habitats for wildlife, and controlling the local climate [11–13]. This recent interest in green space and the function of green infrastructure has emerged [14] due to the multiple functions of ecosystem services [15,16]. Traditionally, green infrastructure refers to large green spaces or connected liner green spaces that are used for stormwater treatment and other management issues [8]. However, in highly dense urban areas where most of the area is covered with impervious surfaces, it is difficult to use a large amount of green space. The indiscriminate expansion of urban areas is exacerbating the urban environment [17], and the importance of green space is increasing. An increase in imperviousness is directly related to an increase in stormwater runoff and damage to the urban water-cycle system [18].

The increase in impervious surfaces in urban areas relates to the deterioration of the water-cycle system and to urban sustainability and resilience. Most studies on urban stormwater treatment have addressed issues on flooding or nonpoint source pollution due to runoff in urban areas, and recently, issues of the urban water-cycle system have increased. In addition, traditional facilities to treat stormwater have primarily included such structures as rain barrels or detention tanks, whereas recent studies have focused on green infrastructure, such as rain gardens, detention ponds, and the whole system of green space.

However, related studies have focused on the capacity and size of green space to reduce runoff [19–21]. Thus, few studies have investigated the effectiveness of using green infrastructure for runoff reduction. In highly dense urban areas, it is hard to plan and create large green space. Most of the large green space in urban areas is located in the outskirts and not in the center of the urban core. However, urban core areas still have small patches of green space and street trees under certain regulations mandating the creation of green space. To use these green spaces and street trees effectively to reduce runoff, knowledge of the effective green space amount, structure, and street-tree type may be important for providing guidance to strategy and policy makers regarding urban runoff management. In this study, we designed a simplified hydrological model to compare each scenario with different green space settings that affect the runoff rate. This study examines the effects of urban green space and street-tree type on runoff reduction, evaluates the factors affecting runoff rate, and explores the most effective green-space planning strategy in the reduction of runoff by urban green space.

2. Materials and Methods

2.1. Simplified Hydrological Model

The existing stormwater runoff models can calculate the exact amount of runoff, but they require a large amount of accurate data, as well as time to simulate. To compare the runoff in different green-space distribution settings with limited data, we used a simplified hydrological model [22]. This model was designed to investigate the effect of different green space distributions on runoff reduction by comparing the total amount of stormwater runoff generated by using virtual watershed settings. The model can set and change the storm event setting, green space distribution and green space type, soil condition, and sewer capacity. The model has been designed to simulate the effectiveness of the different settings of green space on runoff reduction but not to predict the accurate amount of runoff generated from specific spaces and specific storm events.

2.2. Model Flow

The model was designed in three parts to estimate the total amount of runoff (Figure 1). In the first step, the runoff generated from each pervious and impervious cell is calculated. For impervious cells, runoff is calculated by sewer capacity. When the runoff generated in the cell is less than the sewer capacity, it is discharged out of the cell, and no runoff is generated. When the runoff generated in the cell exceeds the sewer capacity, it is calculated as runoff and it flows to the next cell. In the pervious cells, rainfall interception by the tree canopy and infiltration in the soil are employed to calculate the runoff amount.

After calculating the runoff in each cell, runoff from one cell flows into the next cell based on the slope angle and direction of the surface. Runoff flowing into the next cell adds on the calculation of the next cell's runoff (Figure 2). Finally, the total runoff of the whole domain flows into the center bottom cell according to the topography, which is the total runoff amount of the virtual watershed.
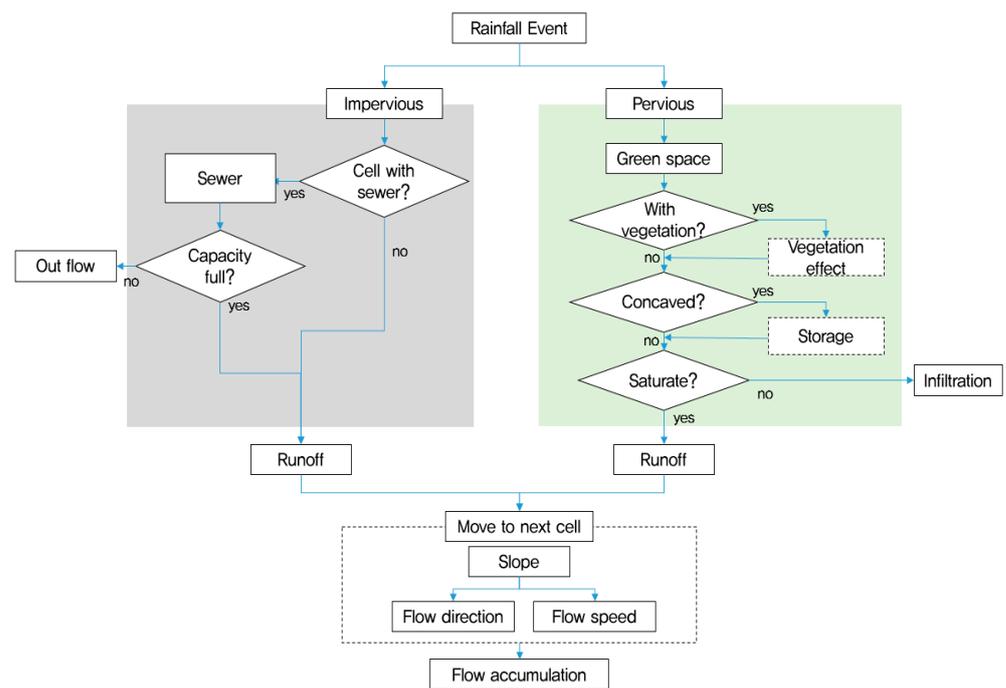
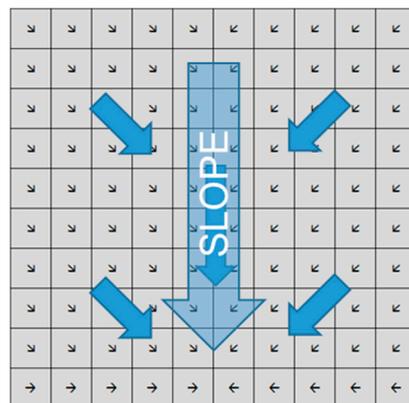**Figure 1.** Flow chart of the simplified hydrological model.

Figure 2. Slope setting for the model.

The process of the total runoff calculation of the whole watershed using each cell's sewer capacity, interception and storage by the tree canopy, and soil infiltration is considered at each time step. The time step continues when the storm event ends and no more runoff flows out from any cell [23].

To apply the urban green space environment type to the model, the common type of street-tree character was included in the model. Trees with different LAI (leaf area index) values were set to simulate the effect of tree canopy interception. The CN (serve number) value of the soil was calculated by using a detailed soil character map and land-cover map of Seoul to calculate the infiltration rate of the soil. The AMC (antecedent moisture condition) I condition of the soil was used to apply the urban environment to the simulation.

The urban settings of buildings, roads, and sidewalks used the typical form of the Seoul urban environment. The domain size was set as 200 m by 200 m with a 2-m by 2-m cell size, and the slope was set to 2.5% evenly over the whole domain. The sidewalk was set at a 4-m width, and one lane of road was set at a 3-m width. The whole domain was divided into four blocks by street with sidewalks and roads that made each block

40 m square, and street trees were placed every 5 m on the sidewalk (Table 1, Figure 3). Buildings were set as 40% of the total area, while roads and sidewalks were set as 35.7%, which made the total impervious surface 75.7%, the average impervious-area rate of the Seoul commercial area. The stormwater sewer was set to cover 200 m^2 with a 120-L size and 1 m^3/min intake capacity (Table 2).

Table 1. Landscape and parameter settings for the model.

Variable	Value
Total area	200 m by 200 m
Cell size	2 m by 2 m (total 10,000 cells)
Landscape slope	2.5%
Sewer size	$40 \times 50 \times 60$ cm (120 L)
Sewer intake	1 m^3/min
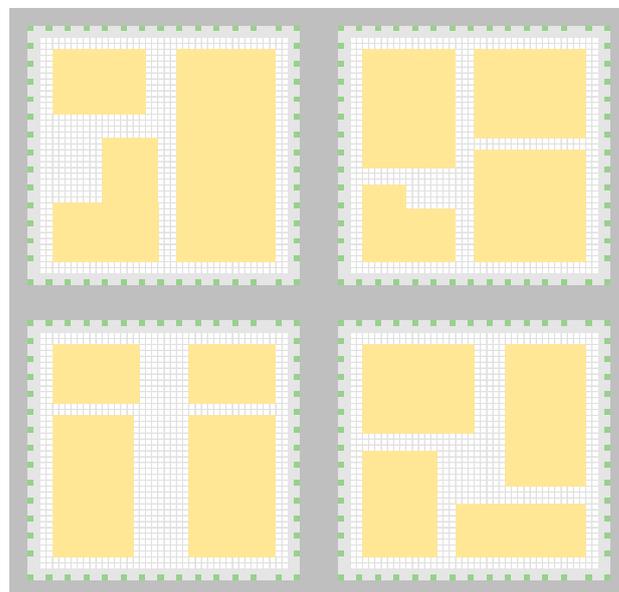
Figure 3. Base land-use setting for the simulation (dark gray is road, light gray is sidewalk, light green is sidewalk with street trees, and yellow is building).

Table 2. Built-environment settings for the simulation.

Feature	Imperviousness (%)	Size (m)	Total Area (%)
Road	100	6 (2 lanes), 12 (4 lanes) width	22.56
Sidewalk	100	4 width	13.14
Building	100	-	40.00

2.3. Scenario Setting

To compare the effect of green space type on runoff reduction, different green space structures were set (Table 3). Different green space area ratios, green space structures (which are components of plants in the green space), types of street trees simulated by different LAI values of tree canopies, and rainfall events with different durations and total amounts were used for scenario setting. The green space area ratio setting was from 5% to 15% at an interval of 2.5%. The green space structure had two types, grass only and tree with grass. The type of street tree was set with different LAIs from 2 to 4 at an interval of 0.5. The storm event was set by using the probable precipitation of Seoul's 30-year storm event record (Table 4). The storm event duration was set from 1 h to 4 h at an interval of

30 min with a total precipitation amount of 94.3 mm. The setting of different total amounts of storm events was set from 94.3 mm to 173.1 mm in two hours at 10-mm intervals. The base scenario was a 10% green space area ratio with grass and trees, street trees with 3 LAI values, and 134-mm storm events for two hours. By changing each parameter, the effects of the green space area ratio, green space type, and street tree type on runoff amount reduction under different storm events were compared. Two parameters changed while the other two parameters were fixed on the base scenario. Finally, to compare best and worst cases, a high green space scenario, which is 15% of green space ratio, street trees with LAI value 4, and trees with grass, was compared with a low green space scenario, which is 5% of green space ratio, street trees with LAI value 2, and only grass in green space while using high intense and low intense rainfall event, set as 173.1 mm precipitation in 1 h and 94.3 mm precipitation in 4 h, respectively.

Table 3. Variable settings for the simulation. LAI: leaf area index.

Variable	Minimum	Maximum	Interval	Number of Scenarios
Green space ratio (%)	5	15	2.5	5
Green space structure	Grass only	Grass with trees	-	
Street tree type (LAI)	2	4	0.5	5
Rainfall duration (hour)	1	4	0.5	7
Rainfall amount (mm)	94.3	173.1	10	9

Table 4. Probable precipitation in Seoul by storm event time from 30 years of records (Ministry of the Interior and Safety, Korea, 2017).

| Storm Event Time	Precipitation (mm)
1 h	94.3
2 h	136.0
3 h	173.1

3. Results

The runoff rate was calculated by comparing the base scenario with a 10% green space area ratio with grass and trees, street trees with a LAI value of 3, and 134-mm storm events for two hours. After changing the green space area ratio and green space structure, the runoff rate decreased more effectively when the green space ratio was over 10% (Figure 4a). The green space structure with grass and trees was more effective as the green space area ratio increased and the runoff rate decreased to 71.6% under 15% of green space area ratio and green space structure with grass and trees. For the scenario with a street-tree type change, while the tree canopy LAI increased, a decrease in the runoff rate was more effective when the green space area ratio was high (Figure 4b). While changing the street-tree type and green space structure, the runoff rate decreased more effectively when street-tree LAI increased from 2 to 2.5 than the other range commonly used for both green space structures. Regardless of the green space structure with grass and trees, the runoff rate decreased more effectively than that with grass only when the LAI value was higher than 3 (Figure 4c).

Changing the storm event duration commonly resulted in a high runoff rate for short-duration and high-intensity storm events. However, the runoff rate decreased effectively as the rainfall duration increased until the duration was 2 h, and it was more effective under a higher green space area ratio (Figure 5a). The scenario under different green space structures showed similar runoff rates during the high-intensity storm event, but the green space structure with grass and trees showed more effective runoff reduction under lower rainfall intensities, which was a 4-h storm event (Figure 5b). The different street-tree types showed greater differences in runoff rate, while the LAI value changed. The runoff rate

decreased sharply from LAI values 1 to 2; however, when the LAI value exceeded 2.5, the runoff rate reduction was not very effective as the value increased (Figure 5c).

The scenarios with different rainfall amounts and green space area ratios of 94 mm in the two-hour storm event showed similar runoff rates of 69.1%, 68.5%, and 67.8%, while the green space area ratios were 5, 7.5, and 10, respectively. However, the runoff rate decreased effectively to 64.4% and 57.9% when the green space area ratio increased to 12.5% and 15%, respectively (Figure 6a). As the rainfall amount increased, the runoff rate increased steeply under the low green space area ratio, while the higher green space area ratio scenario increased gradually. The simulation comparing different green space structures showed that grass with trees reduced the runoff rate by 3.7% under the 94-mm storm event simulation, but as the rainfall amount increased, the gap decreased to 0.9% (Figure 6c). A similar pattern was observed for the different street-tree types with a 7.7% difference in the runoff rate between high and low LAI values under 94-mm storm events and a 3.0% difference under 174-mm storm events (Figure 6c).
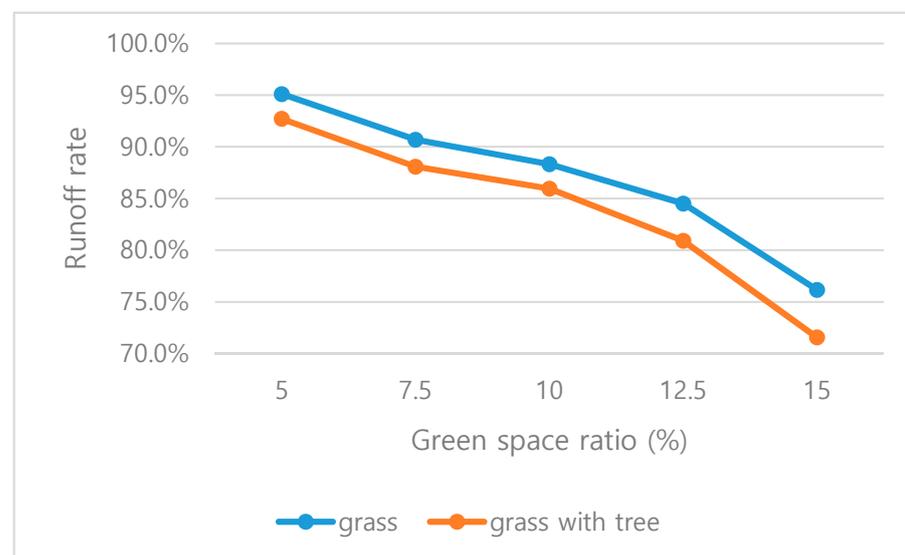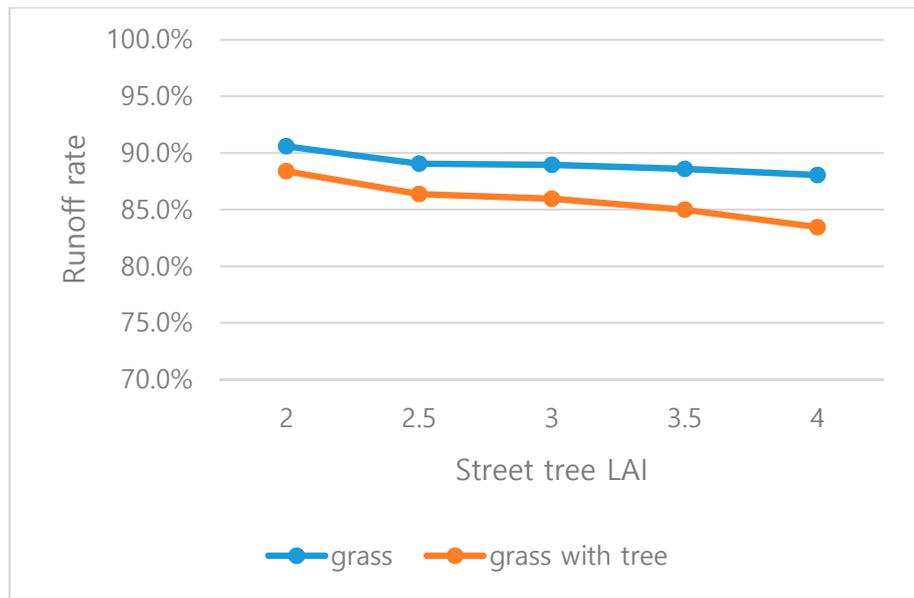

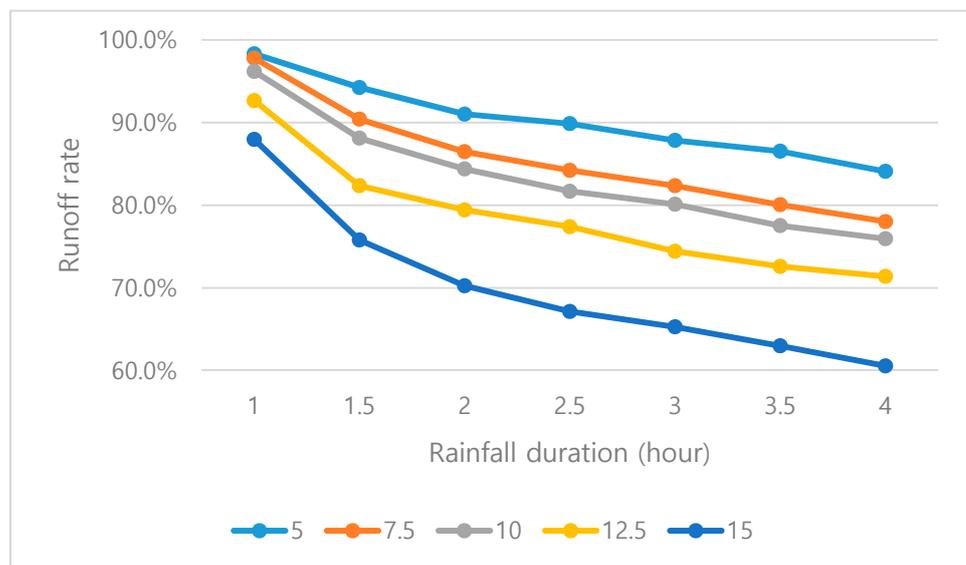(**a**) Green space ratio and green space structure.
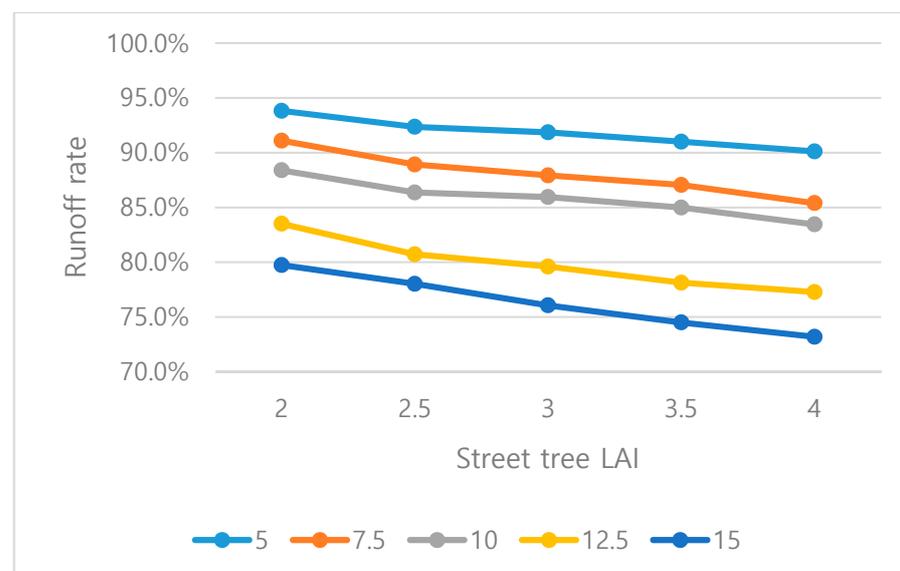
(**b**) Street tree LAI and green space ratio (%).
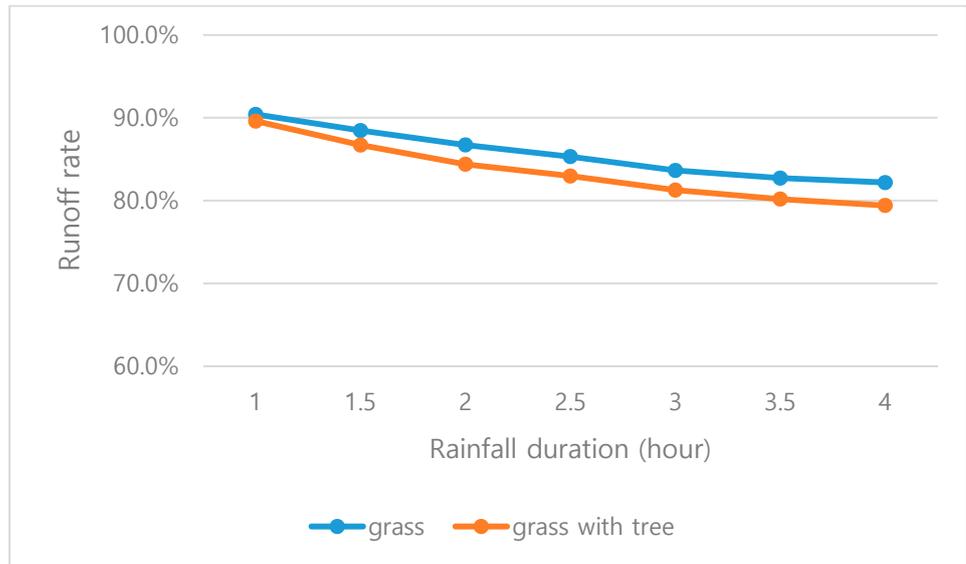
Figure 4. *Cont.*

(**c**) Street tree LAI and green space structure.

Figure 4. Runoff rate under different scenarios. (**a**) Green space ratio and green space structure, (**b**) street-tree LAI and green space ratio, and (**c**) street-tree LAI and green space structure.
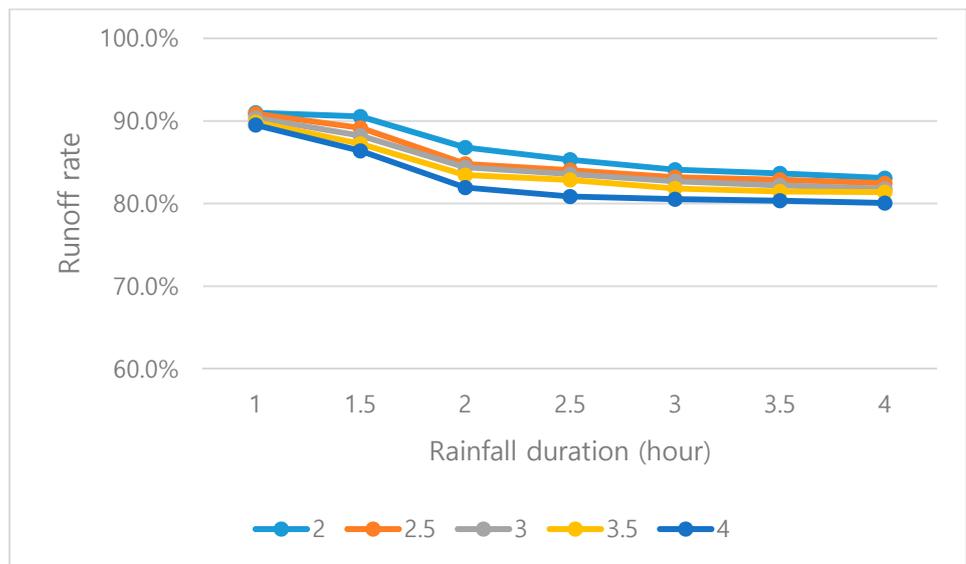

(**a**) Duration and green space ratio (%).

Figure 5. *Cont.*

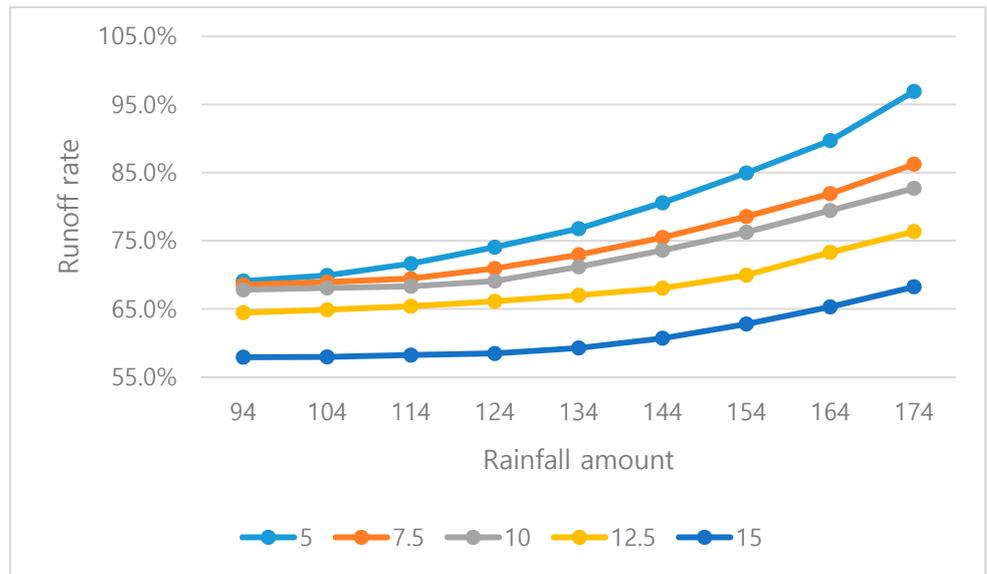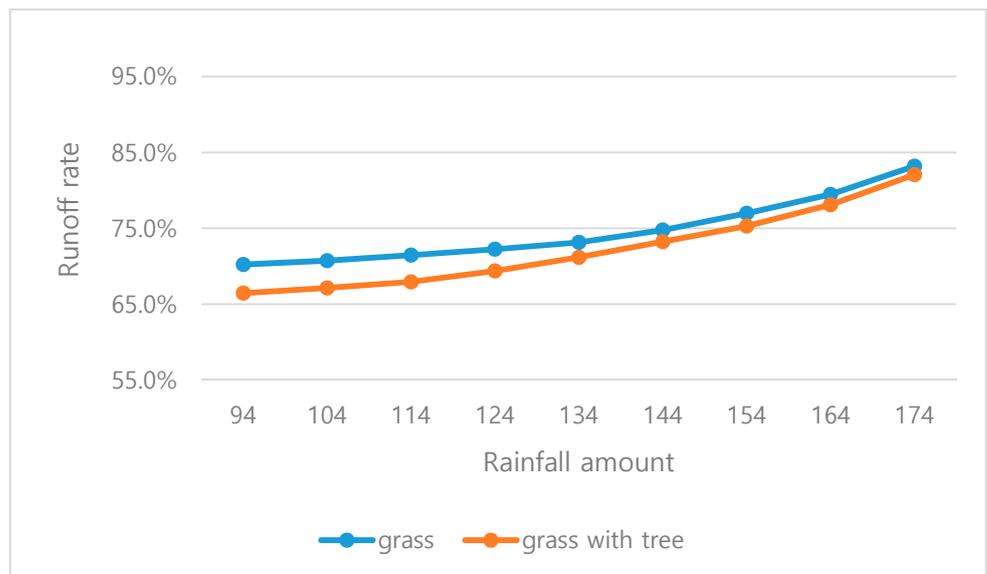(**b**) Duration and green space structure.

(**c**) Duration and street-tree LAI.

Figure 5. Runoff rate under different rainfall durations. (**a**) Duration and green space ratio, (**b**) duration and green space structure, and (**c**) duration and street-tree LAI.
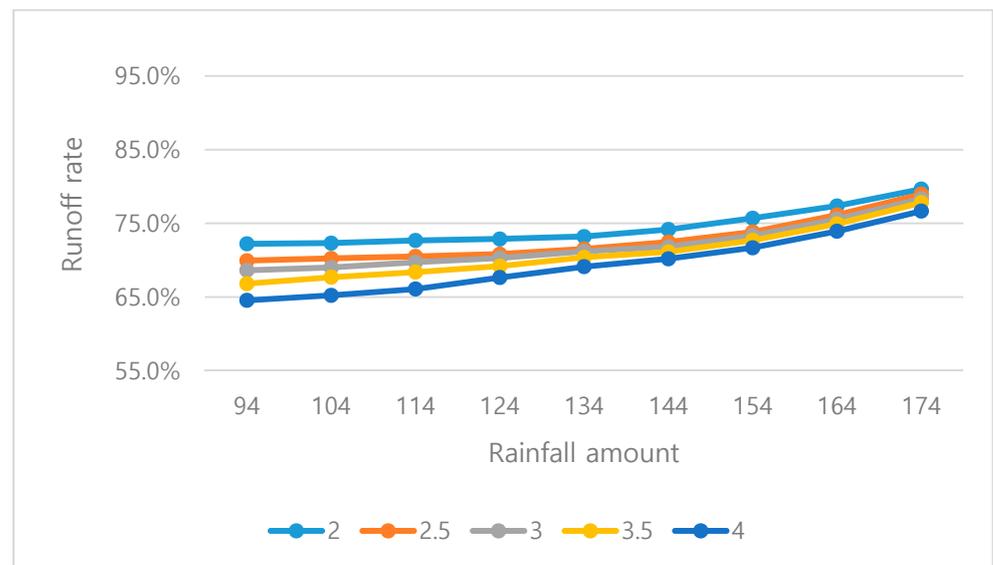
(**a**) Rainfall amount and green space ratio (%).

(**b**) Rainfall amount and green space structure.

Figure 6. *Cont.*

(**c**) Rainfall amount and street-tree LAI.

Figure 6. Runoff rate under different rainfall amounts. (**a**) Rainfall amount and green space ratio, (**b**) rainfall amount and green space structure, and (**c**) rainfall amount and street-tree LAI.

Finally, for the best- and worst-case comparison, the high green space scenario showed 82.9% of runoff rate for a high intense rainfall event and 56.8% of runoff rate for a low intense rainfall event. On the low green space scenario, the runoff rate was 98.2% on a high intense rainfall event and 81.3% on a low intense rainfall event. The high green space ratio scenario had 26.1% of difference between high and low intense rainfall event while the low green space scenario had 16.9% (Figure 7).
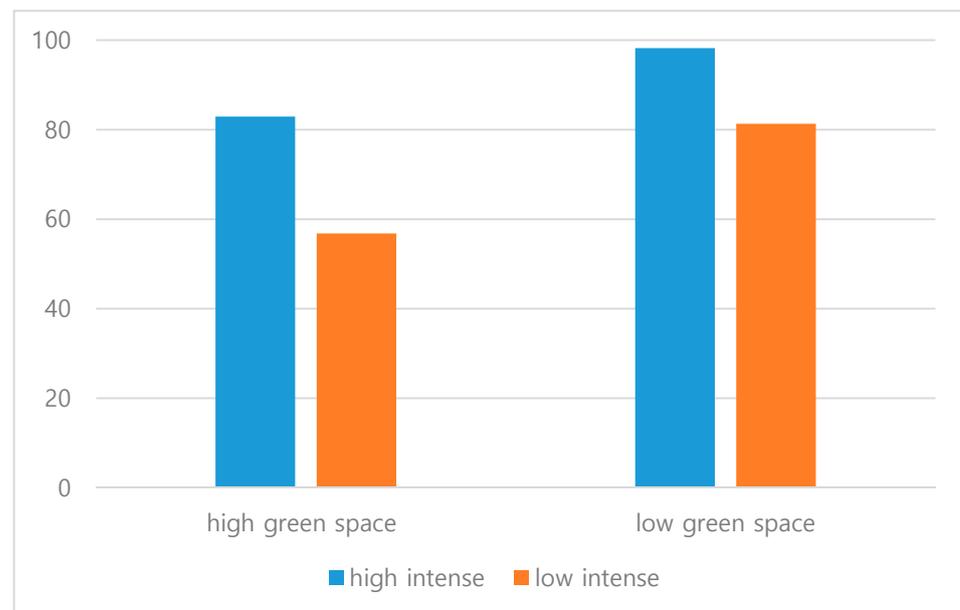
Figure 7. Runoff rate under high and low green space scenario with high and low intense rainfall event.

Overall, the runoff rate decreased as the green space area ratio and LAI of street trees increased or the green space had more structure with trees than grass alone. However, the green space area ratio simulation showed that the runoff reduction effect was higher when

the green space area ratio was higher than 10%, and the street-tree type simulation showed that it was more effective until the LAI value was lower than 2.5. The simulation under high rainfall intensity showed that green space was less effective in treating stormwater. The intensity of rainfall decreased the gap between low and high green space area ratios or increased the LAI value. This finding shows that the effectiveness of stormwater treatment by green space is better under low rainfall intensity, since more green space areas have more capacity to treat stormwater onsite and runoff does not flow to lower areas. For the best and worst scenario comparison, the result showed the high green space scenario still reduces runoff, however, the rate does not reduce effectively on low rainfall intense case. This is because the total amount of tree canopy storage and soil infiltration would be almost full to store or filter more water. It also showed the effectiveness of green space on low intense rainfall since the difference of high and low green space scenario was 15.3% for a high intense rainfall event while it was 24.5% for a low intense rainfall event. Under the condition of less green space area, stormwater is not treated onsite but flows into low areas, accumulating and overflowing, thereby resulting in urban floods.

4. Discussion

This model compared different urban green space settings for runoff reduction using a simplified hydrological model. The model calculated runoff by applying the interception of the tree canopy, infiltration by the soil, and outflow by stormwater sewers. Urban environment setting parameters, including street trees, the green space ratio, and storm events, were determined by using data from Seoul. However, since the model did not use actual storm event data and the model itself was not designed for that purpose, the actual amount of accurate runoff was difficult to derive. Therefore, the results of this simulation were compared with those from previous studies concerning how much urban green space affects runoff reduction [23–27]. The results were consistent with previous studies and showed the effectiveness of urban green space on runoff reduction, especially from small storm events.

The aim of this study is to assist municipal urban planners and landscape planners in designing and formulating policies for the implementation of green space planning. The results of the study suggest that the benefits of green infrastructure are effective for runoff reduction, especially for small storm events. Recently, there has been strong interest in green infrastructure, particularly for stormwater treatment. However, most municipalities still focus on large facilities and construction to remove or store stormwater, rather than treating it onsite. This strategy has already demonstrated its limitations through failure due to the dramatically changing rainfall trends due to climate change. Strategies to treat stormwater onsite by green infrastructure and using gray infrastructure to treat overflow may be the best solutions to treat higher levels of storm event intensity. In addition, for long-term planning, the growth of street trees that affects the LAI value, as well as the trimming of the street trees, needs to be considered. The green space structure also needs to be implemented differently based on its purpose. Where runoff reduction is more important than groundwater recharge, planting more trees with high LAI values may be more important, while creating more concave green space may be better where groundwater recharge is the priority.

The results obtained using the simplified hydrological model are slightly higher than those obtained from similar previous studies [25,27–29], since other external factors may be missing. This property also means that the model only considers direct factors of green space that affect the runoff rate. In the current version of the model, which has a simple structure and input, the model could be transferred to simulate actual sites and urban environment settings by changing the parameters, including sewer capacity, urban structure setting, soil and green space structure, and rainfall event setting. This approach could also implement other LID (low impact development) practices, such as rain gardens, green roofs, and porous paving, by setting parameters by cell.

5. Conclusions

The object of this study was to examine green space on runoff reduction effect and find the most effective green space planning strategy. The results of this study show that a higher green space area rate is more effective, especially when the total rainfall amount and rainfall intensity are high. This finding is due to the green space that includes street trees treating stormwater onsite and generating less runoff, which flows and accumulates in the lowest area. The gap between the high and low green space area ratios increases because the runoff from each area (each cell in this simulation) increases and flows into the lower area (next cell in this simulation), which causes the lower area to be overwhelmed by the rainfall that rains onsite and the runoff from the higher area. This result shows the importance of onsite treatment to reduce runoff. As failures of traditional stormwater treatment systems using a sewer system have recently occurred more often, utilizing green spaces to treat stormwater onsite will reduce pressure on gray infrastructure and will restore urban water cycle systems close to their natural conditions by increasing evaporation, infiltration, and groundwater. Furthermore, green infrastructure also has limitations in that the effectiveness of reducing runoff under high-intensity rainfall is relatively low compared with small storm events. The traditional sewer system in which water rapidly flows out can compensate for the limitation of green infrastructure during short- and high-intensity rainfall events. By utilizing each advantage of green and gray infrastructure to reduce runoff, urban flash floods may be prevented, and the urban water cycle system may be restored. Restoration of urban water cycle systems can reduce flash floods in urban areas and can increase urban resilience. Urban green space planning benefits not only ecological resilience but also economic and social advantages by reducing floods, reducing the heat island effect, and providing social gathering areas [4,30].

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