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Evaluation and Improvement Measures of the Runoff Coefficient of Urban Parks for Sustainable Water Balance

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Abstract: As the impermeable sidewalk area increases in urban areas, diverse problems related to water occur. The purposes of this research were to increase the rainwater infiltration rate through water balance analysis and estimate the runoff coefficient according to land cover types in urban parks. The regression equations and runoff coefficients relative to the rainwater infiltration rate were estimated according to the land cover types and applied to eight urban parks. In the results of the experiment, the runoff coefficient was 0.245 for vegetation areas, 0.583 for permeable sidewalks, 0.963 for sidewalk blocks, and 1.000 for impervious sidewalks, which had 100% outflow. The results show that the vegetation area in urban parks is significantly related to rainfall–runoff, infiltration, and evapotranspiration. The average of eight urban parks was 126.52 mm, indicating that 11.80% of the rainfall was recharged into groundwater. Additionally, the average runoff rate was 498.56 mm, indicating that 46.52% was leaked externally. Therefore, it is suggested to decrease the impermeable sidewalk areas in urban parks. Additionally, extending the waterway, swamp, and gravel sidewalk areas is suggested. Urban parks should be developed in order to contribute to hydrological control through the water balance in urban land use.

Keywords: ecosystem service; urban; impervious; recharge; rural

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1. Introduction

Korea's urban development has been conducted to improve people's lives [1], and the world's promotion of urban development is expanding rapidly [2]. Modifications to plans in urban development are due to environmental and economic changes and overpopulation, and various problems arise regarding the natural environment and urban landscape [1,3,4]. Advancement and indiscreet exploitation due to urban development negatively influence environmental and ecological sectors [5–8] and fail to meet citizens' needs for green space and natural environments [9–11].

The increase in the impermeable layer due to intensive land use is the most common cause of these urban issues [12], and it has distorted the hydrological cycle and caused waterlogging, the heat island phenomenon, and the ecosystem disturbance [13–16]. According to the Ministry of Environment, Seoul's impermeable area as of 2013 was 54.37%, and the external precipitation leakage amounted to approximately 81% [17]. Rapid external water leakage during rainfall is a worldwide urban problem [18]. The increased impermeable ground surface caused by urbanization causes temporary rainfall leakage into rivers, triggering river water pollution [19], groundwater depletion due to the decreased runoff infiltration rate [18], stream drying [19], difficulties in securing water resources [20], urban heat islandization [20], and ecosystem disruption [19]. The problems from expanding the impermeable area go beyond cities and induce problems in rural and agricultural districts [20–24]. Groundwater recharge is a vital ecosystem service function [25,26], and agricultural regions have been found to have an excellent groundwater recharge function [27,28]. However, expanding the impermeable area makes it challenging to recharge groundwater [29–32].

The difficulty in cultivating groundwater depletes the groundwater [33–37], decreasing the amount of water humans can utilize [38–42]. Water shortage globally has been brought on by suppressing efficient water distribution and transport [43,44].

To solve water shortages and problems in the hydrological cycle, groundwater recharge in cities is being improved, and methods of using parking lots, urban parks, sports complexes, government offices, and other national and public facilities as primary spaces are being sought [45,46]. Basic urban ecosystem and environmental improvement goals include replenishing the natural soil [47,48], supplying minimum impact development facilities [49,50], and removing impermeable areas [51,52]. However, replenishing natural soil in an urban space carries the difficulty of restoring an already developed city [53,54]. Therefore, enhancing the function of an already created urban park is appealing.

Urban parks function as diverse environmental and ecological ecosystem services [55,56]. Previous studies have recognized the effects of groundwater recharge [57,58], heat island alleviation [59–61], contaminant reduction [51,58], air quality improvement [62–66], recreation [67,68], biodiversity [69,70], landscape improvement [71,72], education [73,74], and urban agriculture [75,76]. Among these, groundwater recharge is critical for enhancing the urban hydrological cycle [77,78], and the need to use urban parks for improving the urban hydrological cycle has been reported [79–86].

Furthermore, the rational formula evaluation model to interpret the urban hydrological cycle is examined by calculating precipitation as the sum of evapotranspiration, the infiltration rate, and the runoff rate [87–89], and evapotranspiration can be interpreted using a formula, albeit complex, using meteorological data, including temperature, humidity, and air pressure [90,91]. Therefore, it is structured to calculate the infiltration rate by accurately interpreting the runoff rate [90,91]. The runoff rate is calculated by multiplying the runoff coefficient, rainfall intensity, and area, but it has a drawback because the value varies depending on the value inserted for the runoff coefficient. Data divided as soil texture and land cover types are used for the runoff coefficient employed in hydrological water balance analysis [26,27]; however, it is challenging to apply the runoff coefficient to research because the coefficient range is broad and land use division is ambiguous [92,93]. Hence, setting the runoff coefficient is paramount in water balance analysis [94].

Thus, this study identified the precipitation runoff coefficient for water balance analysis according to sidewalk materials using the groundwater infiltration rate and evapotranspiration calculation results. The experimental outcomes were used to analyze the runoff coefficient, groundwater recharge, and rainfall runoff rate concerning the impermeable cover types of urban parks and interpret the water balance.

Consequently, this study determined the contribution value of eco-friendly sidewalk forms for cultivating water resources and sought ways to heighten the recharge of water resources in parks in cities. By applying the results, improving the impermeable area in urban parks was suggested to proactively resolve problems in the urban hydrological cycle.

2. Experimental Materials and Methods

This study proposes continual urban park expansion by evaluating urban parks' water resource cultivation ability and urban hydrological cycle contribution. This study comprised the following stages: First, we examined the test for measuring the groundwater infiltration rate (Section 2.1). Second, we calculated the groundwater infiltration rate and runoff coefficient of the land use types using the groundwater infiltration measurement result and hydrological cycle evaluation (Section 2.2). Third, we interpreted the water balance in eight urban parks (Section 2.3) and evaluated the statistical relationships based on the assessed runoff rate, penetration data, and land use ratio of the study sites. The detailed materials and methods are discussed below.

2.1. Test for Measuring the Groundwater Infiltration Rate

This study used the following method to propose an improvement measure for cultivating groundwater in urban and rural regions. First, the typical impermeable areas that can be improved in urban and rural regions were designed using asphalt and concrete sidewalks (Is), and vegetation area (Va), permeable sidewalks (Ps), and some pervious sidewalks (SPs) were selected as the sidewalk forms for comparison (Figures 1 and 2). The runoff coefficient and water balance analyses were performed on four sidewalk forms. For the composition of the test structure, the ground was dug as shown, and Gee 3 was constructed to classify the packaging materials, as shown in Figure 1.

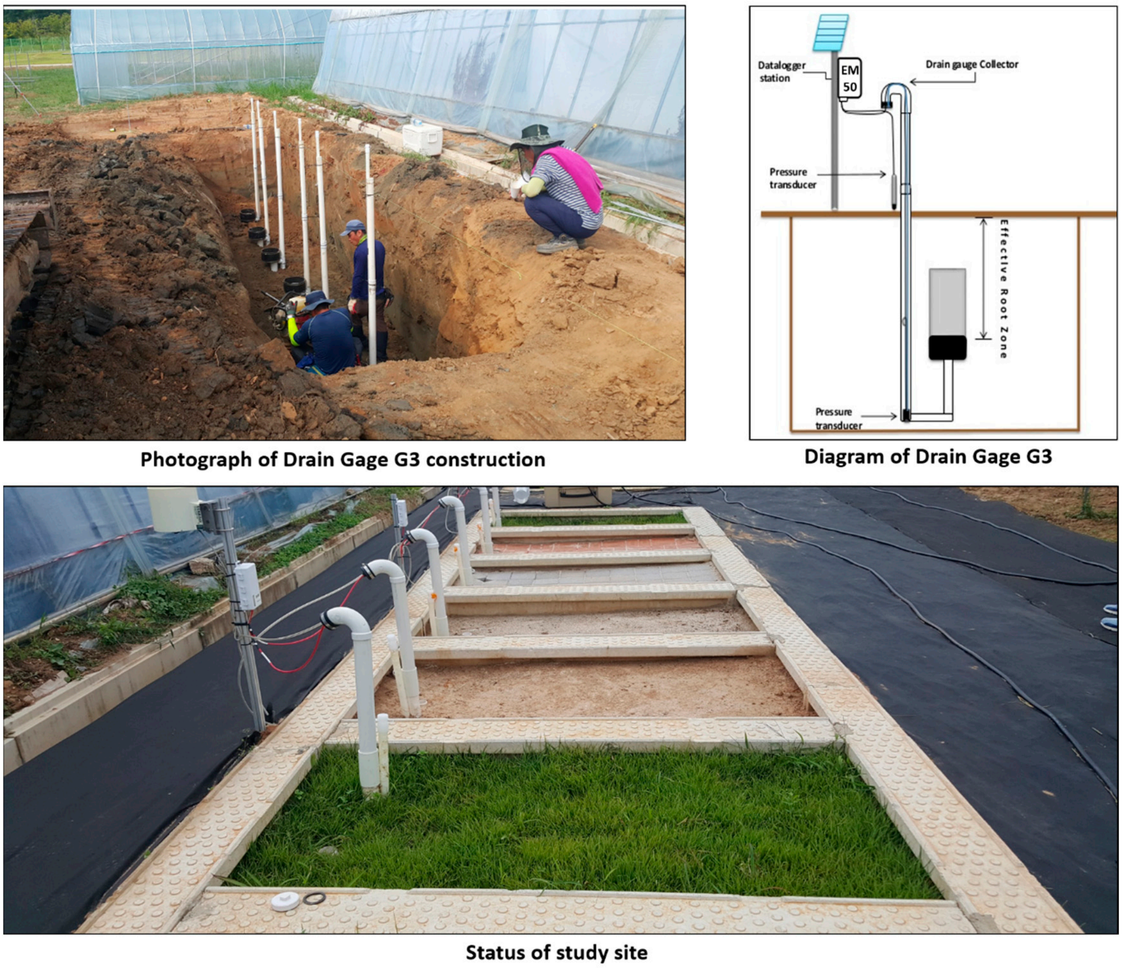

Figure 1. Photograph of Drain Gage G3′s construction, diagram, and status.

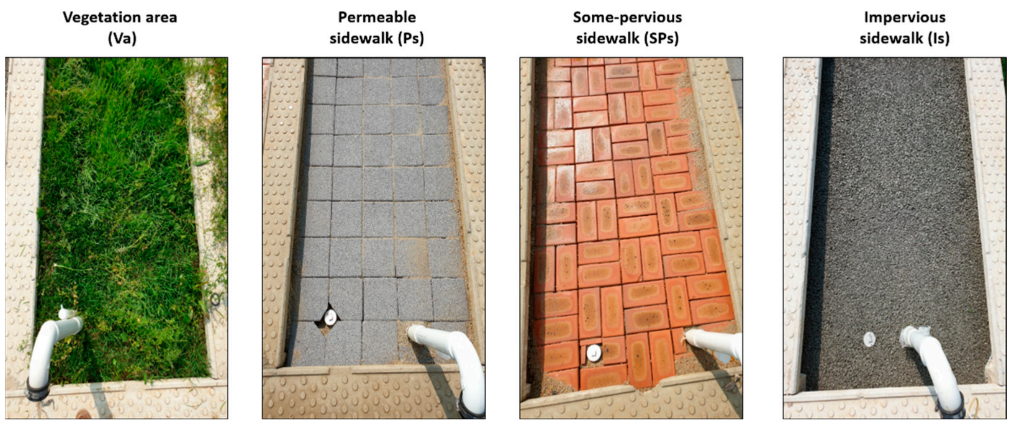

Figure 2. Classification of experiments according to 4 ground materials.

The experimental sites’ precipitation was measured, and the relevant region’s evapotranspiration was assessed according to the model. Thereafter, the groundwater infiltration rate was surveyed to calculate the runoff coefficient, and the runoff coefficients evaluated per sidewalk form were applied to the water balance analysis.

The groundwater infiltration rate survey calculated the runoff coefficient for assessing the runoff rate and the penetration equation for assessing the infiltration rate, and it was evaluated through an on-site measurement of the groundwater infiltration rate per sidewalk material. First, precipitation was measured using Decagon Devices' EM50 Digital Data Logger, and the same company's Gee lysimeter (drain gage) was used for the groundwater infiltration rate (Figure 1).

As shown in Figure 2, Drain Gage G3 allows observing the infiltration rate for a specific period by filling the soil in a cylinder with a constant volume and measuring the water infiltrated from precipitation and irrigation water using a wick intercepting device [95]. The water collected through Drain Gage G3 is measured in real time by the unit of pressure and is saved in the data logger (EM50). Then, it is converted into volume and indicated by mm. In this study, 56.7 mL was calculated as 1 mm of precipitation infiltration height based on the measurement value in mm measured from the sensor and setting the water infiltrated from the groundwater as 506.7 cm^2, the cylinder's width.

2.2. Method for Calculating the Groundwater Infiltration Rate and Runoff Coefficient

The evaluation of the water balance interpretation of the urban parks was conducted using the rational formula method, most widely known in hydrological cycle evaluation [89]. As presented in Equation (1), the total annual precipitation in the relevant region was calculated on the assumption that it comprises the annual external runoff rate, soil infiltration rate, and evaporation.

$$P = \text{Potential evapotranspiration } (PET) + \text{ Runoff rate } (Q) + \text{ Underwater infiltration rate } (I), \quad (1)$$

where P is the annual precipitation (mm), PET is the annual potential evapotranspiration rate (mm), and I is the total annual infiltration rate (mm).

Water balance interpretation using the formula method indicates the total runoff of the relevant region and is calculated as $Q = 0.2278 \times C \times I \times A$. Setting the runoff coefficient is crucial because the relevant region's total runoff rate varies depending on the runoff coefficient inserted here [94]. However, most studies derive the evaluation outcomes by inserting a generalized value for the runoff coefficient, so this value is extremely subjective [96].

Therefore, this study used the rational formula by modifying Equation (2) to calculate the water balance per land use in the study region. For the water balance, hydrological variables that are challenging to quantify, such as the lateral runoff and regression quantity, were excluded, and the water balance was calculated using surface runoff, the infiltration rate, the evapotranspiration rate, and precipitation. The modified rational formula used in this study was calculated based on the rational formula and the runoff coefficient applied to the rational formula, and the concept proposed by Mulvaney [89,97], Donahue [97], and the American Society of Civil Engineers (ASCE) [98] was fully adopted for the runoff coefficient.

$$P - (C \times P) - \{(1 - C) \times PET\} - I = 0, \quad (2)$$

When no runoff (100% permeable land cover) occurs, only evapotranspiration and infiltration occur in the research area; the infiltration rate is calculated from the difference between the precipitation and evapotranspiration rates. However, when runoff occurs at the same rate as precipitation (100% impermeable land cover), no infiltration and evapotranspiration occur. The hydrological components can be calculated per land use in the research area using the modified rational formula, and the hydrological components in the entire research area can be calculated using the weighted method per land use area. The rainfall material (P) of the region targeted for evaluation must be secured to explain this process and to assess PET and diverse weather, including humidity, temperature, and air pressure, and data must be identified and evaluated by the sum throughout the research period [91].

As inferred from Equations (1)–(3), calculating the runoff coefficient is crucial for water balance analysis, and the groundwater infiltration rate (S) must be interpreted through precipitation investigation and evapotranspiration calculation.

$$\lambda E = \frac{\Delta(H_{nr} - G) + P_{air} \cdot C_p \cdot \left[e_z^0 + e_z\right]/r_a}{\Delta + \Gamma\left(\alpha + \frac{r_c}{r_a}\right)}, \tag{3}$$

where λE is the latent heat intensity (MJ/m^2·d), E is the evaporation rate depth (mm/d), Δ is the temperature curve slope of the saturated water vapor pressure (de/dT, kPa/°C), H_{nr} is the net radiation (MJ/m^2·d), G is the heat flux density to the ground (MJ/m^2·d), P_{air} is the air density (kg/m^3), C_p is the specific heat at a constant pressure (MJ/m^2·d), e_z^0 is the saturated water vapor pressure at height z (kPa), e_z is the water vapor pressure at height z (kPa), γ is the psychrometric constant (kPa/°C), r_c is the plant canopy resistance (s/m), and r_a is the aerodynamic resistance (s/m).

Hence, the infiltration rate was measured per sidewalk material (Equation (4)) and inserted in the modified rational formula to find a suitable runoff coefficient (C) used for the hydrological cycle interpretation according to the sidewalk material.

$$I1 = P - (C \times P) + \{(1 - C) \times PET\}, \tag{4}$$

where P is the total annual precipitation (mm), C is the runoff coefficient ($0 < C < 1$), PET is the annual potential evapotranspiration rate (mm), and I is the total annual infiltration rate (mm).

Thus, this study's runoff coefficient per sidewalk material can be applied to urban parks targeted for research to evaluate the runoff rate ($Q1$). Considering Equations (1)–(4), the infiltration and evapotranspiration rates can be assessed by calculating the runoff coefficient, but the evapotranspiration rate used in the equations is the total annual evaporation, inherently carrying uncertainty in the relationship with the actual infiltration rate. Therefore, this study derived the runoff coefficient's calculation using Equation (4) by measuring the infiltration rate, and the actual infiltration rate was identified using Equation (5) from the statistical processing using the results summarized from the survey data.

$$\text{Infiltration rate } (I1) = \text{ Proportional constant } (\alpha) \times \text{ Precipitation } (P) + \text{ General constant } (b) \tag{5}$$

Therefore, Equation (6) shows the water balance analysis equation according to the land use forms in urban parks and rural areas used in this study. The water balance analysis compared to precipitation in the relevant area was assessed by deriving the runoff rate indicated as $Q1$ and the infiltration rate indicated as $I1$.

$$\text{Precipitation } (P) - \text{Runoff rate } (Q1) - \text{Infiltration rate } (I1) - \text{Evapotranspiration } (E) = 0 \tag{6}$$

2.3. Interpretation of the Water Balance in Urban Parks

This study's spatial scope selected eight urban parks in the Korean metropolitan area. The selection criteria for the sites followed Korea's park installation regulations, and the following were selected: four neighborhood parks in a neighborhood unit (living zones 1–4) and four neighborhood parks in a walking sphere of 30,000 m^2 or larger (Table 1).

Eight urban parks were selected as the study sites, and the land cover status was analyzed using aerial photography (DJI's Phantom 4 drone) and design drawings (Figures 3 and 4).

Table 1. Selection of study sites for evaluating the water balance of urban parks.

Classification	Location	Area		
		Total (ha)	Green Space	
			(ha)	(%)
Urban Park within a Living Zone (Over 10,000 m^2)				
Life 1	1326, Wadong-ri-dong, Paju-si, Gyeonggi-do	2.16	1.31	60.65
Life 2	1101, Donae-dong, Goyang-si, Gyeonggi-do	2.93	1.86	63.48
Life 3	1078, Donae-dong, Goyang-si, Gyeonggi-do	1.31	0.91	65.00
Life 4	Wonheung-dong, Goyang-si, Gyeonggi-do	1.65	1.31	79.39
Neighborhood park within a walking sphere (over 30,000 m^2)				
Walk 1	1640-1, Unnam-dong, Jung-gu, Incheon	4.84	3.07	63.43
Walk 2	363, Dongsan-dong, Deogyang-gu, Goyang-si	9.03	5.93	65.67
Walk 3	603, Yeonsu-dong, Seongnam-si, Gyeonggi-do	3.02	2.21	72.65
Walk 4	371, Dongsan-dong, Goyang-si, Gyeonggi-do	6.04	4.54	75.17

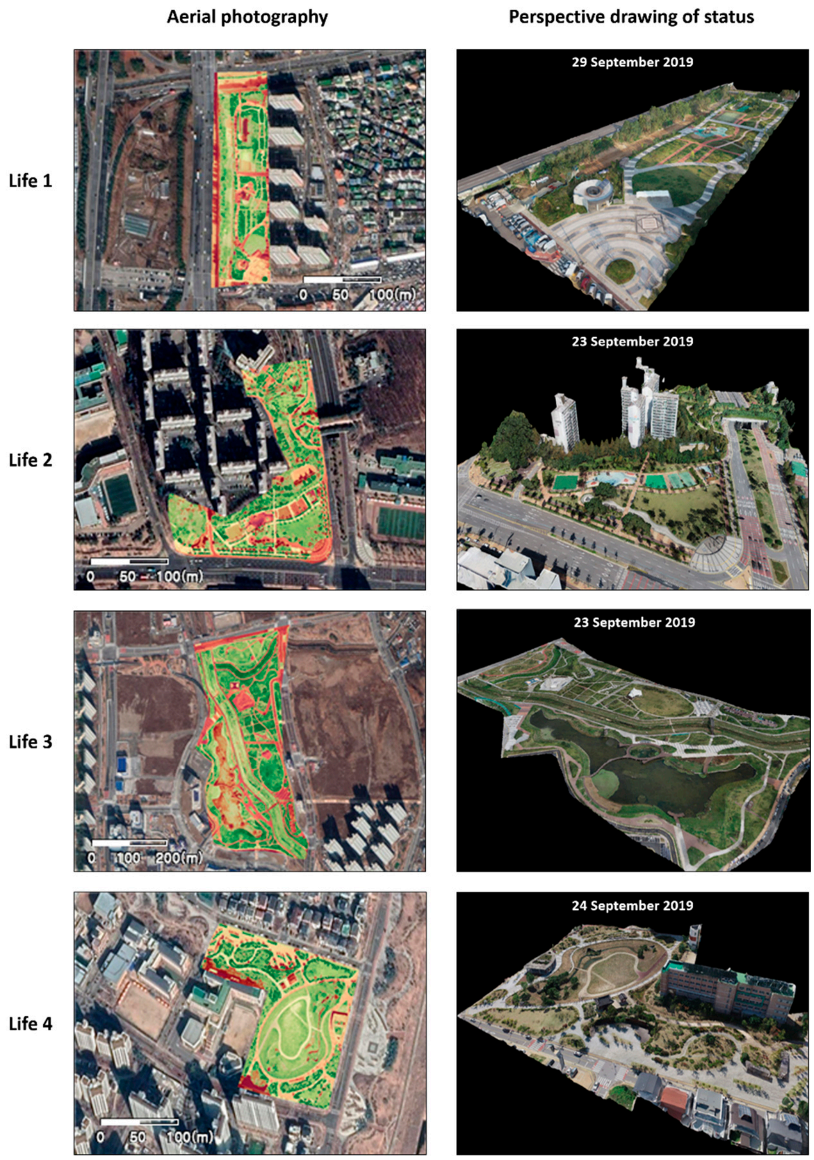

Figure 3. Photos of the land cover status of the living zones-4 study sites.

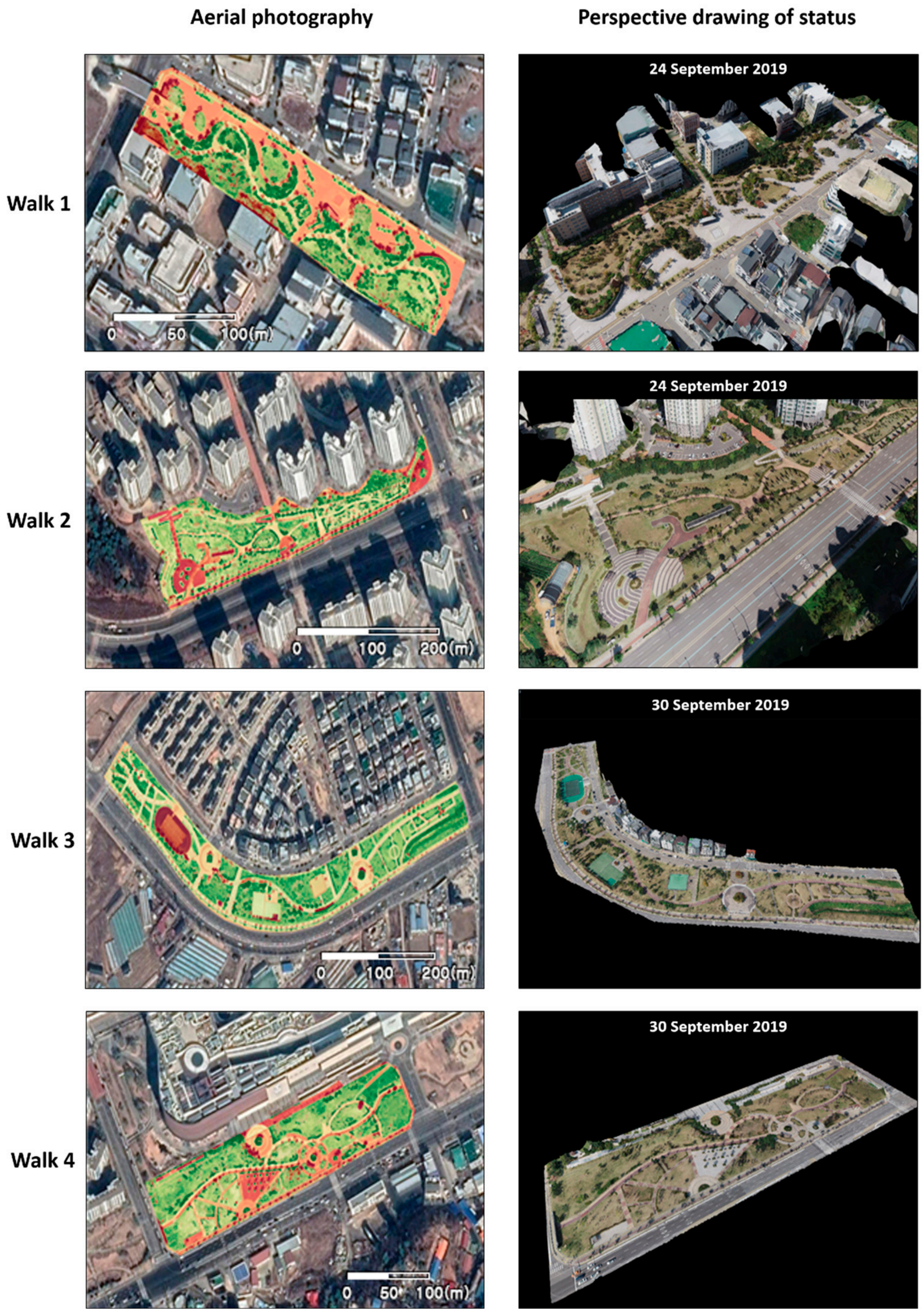

Figure 4. Photos of the land cover status of the walking spheres-4 study sites.

The study sites' flight paths were set for aerial photography and reported to the administrative management officer. After obtaining approval, the photography was conducted using an autopilot device. The photographed video was uploaded as an image and underwent a matching process followed by a point cloud collection process of embodying the final photographed video. The photographed videos were distinguished as 2D orthophotos and 3D models and are presented in Figures 3 and 4.

The green areas were divided based on the analyzed details, and the sidewalk materials were identified through the field survey. The sidewalk materials distinguished from the field survey were categorized into vegetation areas, some pervious sidewalks, permeable sidewalks, and impervious sidewalks, and the water balance was assessed.

3. Results

3.1. Analyzing the Groundwater Infiltration Rate per Sidewalk Material

The experimental area's precipitation in 2018 was 1194.4 mm, which was analyzed to be similar to Korea's annual average precipitation. The experimental sites experienced 122 rainy days, and the monthly accumulated precipitation was the highest in July (252.4 mm). Before measuring the groundwater penetration per typical sidewalk material of urban parks, the monthly data from the Jeonju meteorological station were collected for the relevant area's daily evapotranspiration.

Table 2 shows the measurement results of groundwater penetration per typical sidewalk covering material at the experimental sites. The annual penetrated amount was 214.51 mm, with a penetration ratio of 17.96% compared to the total precipitation on grass (vegetation area, Va), and the largest amount of 44.69 mm occurred in July. July received the highest precipitation (approximately 50 mm) and penetration of 5.875 mm. In total, 118.45 mm penetrated annually into permeable blocks (permeable sidewalk, Ps), with a penetration ratio of 9.92% compared to the precipitation. The maximum penetration occurred in July (22.70 mm). Clay blocks (some pervious sidewalk, SPs) were penetrated by 10.43 mm annually, which can be assessed as 0.87% compared to the precipitation and was found to be less than 10% of the permeable sidewalk. Concrete (impervious sidewalk, Is) was found to have no penetration.

Table 2. Analysis of monthly groundwater penetration.

Item	Weather Status		Va		Ps		SPs		Is	
	Precipitation (mm)	Evapotranspiration (mm)	Penetration (mm)	Ratio (%)	Penetration (mm)	Ratio (%)	Penetration (mm)	Ratio (%)	Penetration (mm)	Ratio (%)
January	25.2	22.74	5.63	22.33	2.85	11.33	0.34	1.34	0	0
February	31.5	35.51	6.99	22.20	3.83	12.16	0.12	0.39	0	0
March	67.1	61.66	14.90	22.21	9.12	13.59	0.50	0.74	0	0
April	144.2	88.55	25.09	17.40	14.45	10.02	1.38	0.95	0	0
May	84.3	106.1	18.38	21.81	10.53	12.49	0.67	0.79	0	0
June	95.2	118.1	17.83	18.73	10.05	10.56	0.67	0.70	0	0
July	252.4	145.5	44.69	17.71	22.70	9.00	2.91	1.15	0	0
August	34.6	134.7	9.11	26.32	4.50	13.02	0.28	0.82	0	0
September	135.6	83.59	25.60	18.88	11.76	8.68	0.71	0.52	0	0
October	163.3	57.27	23.44	14.35	14.60	8.94	1.83	1.12	0	0
November	102.8	32.91	15.61	15.19	9.08	8.83	0.69	0.67	0	0
December	58.2	23.67	7.24	12.44	4.97	8.54	0.35	0.59	0	0
Total	1194.4	910.3	214.51	17.96	118.45	9.92	10.43	0.87	0	0

The ratio is the monthly precipitation to the penetration proportion; for evapotranspiration, the *PET* of Equation (3) was calculated based on the air pressure data of the meteorological station in the Jeonju area, the experimental region.

When inserting the relevant data into $I1 = P - (C \times P) - \{(1 - C) \times PET\}$, the modified rational formula proposed in the research method can be set as $I1 = 1194.4 - (C \times 1194.4) - \{(1 - \mathrm{C}) \times 910.3\}$. In the rational formula evaluation used in the Korean sewerage facility criteria [99] and adopted by the ASCE [98], United States Geological Survey [100], and Solano County Water Agency [101], some cases have a runoff coefficient of up to 1.0 for wetlands. However, the relevant coefficient was calculated assuming there is an outlet in a saturated state. The regression equation was derived using the experimental area's monthly precipitation for the groundwater infiltration rate per typical sidewalk material measured.

First, 12 monthly precipitation-to-penetration data of the vegetation area were graphed, and the first regression equation was derived. Consequently, the regression equation for vegetation area (Va) was calculated as y (penetration) = 0.1648 × (precipitation) + 1.3598, and the R^2 value indicating statistical significance was remarkably high at 0.9547. Similarly, the regression equation for permeable sidewalk (Ps) was calculated as y (penetration) = 0.0862 × (precipitation) + 1.1899 (R^2 = 0.9637), and that for clay blocks (some pervious sidewalk, SPs) was calculated as y (penetration) = 0.0111 × (precipitation) + 0.2157 (R^2 = 0.9063) (Figure 5). These equations show that penetration is closely related to precipitation. The amount of penetration by land use tested can be interpreted as an analyzed equation.

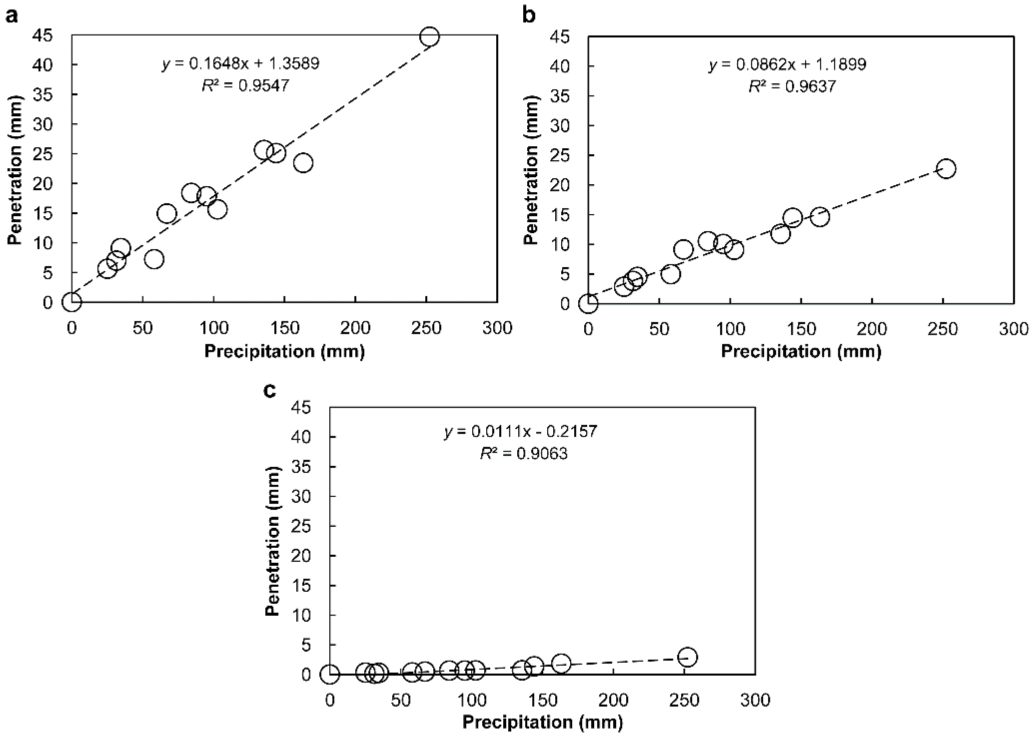

Figure 5. Amount of groundwater penetration compared to the monthly precipitation of the three ground materials: (**a**) regression equation for the vegetation area (Va) penetration; (**b**) regression equation for the permeable sidewalk (Ps) penetration; (**c**) regression equation for the some pervious sidewalk (SPs) penetration.

3.2. Calculating the Runoff Coefficient According to the Land Cover Types

The groundwater penetration test results of Va, Ps, SPs, and Is measured at the experimental sites and the hydrological rational formula runoff rate evaluation results were analyzed to calculate the relevant sidewalk environment's runoff coefficient. The calculated runoff coefficient was applied to urban and rural areas to calculate the runoff infiltration rate, and it can be evaluated using the modified rational formula (Equation (4)) proposed in previous research. Here, the measured values can be applied to the precipitation and penetration values; therefore, finding the annual evapotranspiration rate of the relevant area allows for calculating the runoff coefficient.

The total precipitation in Jeonju in 2018 was 1194.4 mm, and evapotranspiration was found to be 910.3 mm, assuming there was no runoff. Table 2 shows the monthly evapotranspiration rate.

When inserting the relevant data into $I1 = P - (C \times P) - \{(1 - C) \times PET\}$, the modified rational formula proposed in the research method ($I1 = 1194.4 - (C \times 1194.4) - \{(1 - C) \times 910.3\}$) can be set. Here, when inserting the penetration of grass and the permeable sidewalk into $I1$, the C value (runoff coefficient) can be calculated. C can be inserted into the infiltration rate ($Q1$) = $C \times P$ to interpret the runoff rate. Based on the evaluation data of $I1$ and $Q1$, evapotranspiration (E) = precipitation (P) − infiltration rate ($I1$) − runoff rate ($Q1$) can be interpreted to complete the water balance.

The underground penetration of concrete (Is) was measured as 0 mm, and the runoff coefficient was 1.000. When interpreting this as a rational formula, the evapotranspiration rate can be interpreted as 0 mm and the runoff rate as 1194.4 mm. The groundwater penetration of grass (vegetation area, Va) was measured as 214.5 mm; thus, the runoff coefficient was 0.245. When interpreting this with a modified rational formula, the evapotranspiration rate can be interpreted as 687.3 mm and the runoff rate as 292.6 mm. The groundwater infiltration rate of the permeable sidewalk (Ps) was measured as 118.45 mm, and the runoff coefficient was 0.583. When interpreting this with the rational formula, the evapotranspiration rate can be interpreted as 379.6 mm and the runoff rate as 696.3 mm. The groundwater infiltration rate of some pervious sidewalk (SPs) was measured as 10.43 mm, and the runoff coefficient was 0.963. When interpreting this with the rational formula, the evapotranspiration can be interpreted as 33.7 mm and the runoff rate as 1150.2 mm. The vegetation area's (Va) runoff coefficient (0.245) had a maximum value of 0.05–0.250—the coefficient of a park with a lawn in the Korean sewerage facility criteria [99]. It was assessed as an extremely high runoff coefficient compared to the 0.05–0.10 of grass plains (sandy soil, 2% slope)—a coefficient used in the rational formula evaluation model proposed by Mulvaney in a study related to a typical runoff coefficient [96]. Moreover, although brick blocks had a coefficient of 0.70–0.85 in previous studies, this study proposes that the runoff coefficient must be continuously studied for comparison through additional experiments because brick blocks were found to have a coefficient of 0.963 in this study [102–106]. By using the following experimental method, the runoff coefficient's calculation can generate data that complement the drawbacks of previous studies, where differences occur in calculating the runoff coefficient due to the user's subjectivity [107]. The runoff coefficient and water balance equation per sidewalk material of the six evaluated types can be used for projects aimed at improving urban groundwater cultivation.

3.3. Analyzing the Land Cover Forms of Urban Parks

For the eight urban parks, the lowest green area ratio was 60.6%, and the highest was 79.4%, indicating an average of approximately 68.2% (Table 3).

Table 3. Analysis of the status of the land cover of the study sites.

Study Sites	Total Area	Va	Ps	SPs	Is	Other
Life 1 (m^2)	21,599.1	13,100.0	642.9	3723.6	2643.6	1490.0
Ratio (%)	100.0	60.6	3.0	17.2	12.2	6.9
Life 2 (m^2)	29,300.0	18,600.0	929.2	9502.9	0	267.9
Ratio (%)	100.0	63.5	3.2	32.4	0.0	0.9
Life 3 (m^2)	14,000.0	9100.0	0.0	4516.8	197.5	185.7
Ratio (%)	100.0	65.0	0.0	32.3	1.4	1.3
Life 4 (m^2)	16,500.0	13,100.0	0.0	1732.9	1559.3	107.8
Ratio (%)	100.0	79.4	0.0	10.5	9.5	0.7
Walk 1 (m^2)	48,400.0	30,700.0	5248.5	9289.4	3032.3	129.8
Ratio (%)	100.0	63.4	10.8	19.2	6.3	0.3
Walk 2 (m^2)	90,300	59,300.0	2613.2	22,984.3	5402.5	0.0
Ratio (%)	100.0	65.1	2.9	26.2	5.9	0.0
Walk 3 (m^2)	30,489.0	22,150.0	978.6	1355.9	4852.7	1151.8
Ratio (%)	100.0	72.6	3.2	14.4	5.7	3.8
Walk 4 (m^2)	60,400.0	45,400.0	958.0	8957.9	4556.0	528.1
Ratio (%)	100.0	75.2	1.6	14.8	7.5	0.9

The field investigation showed that the sidewalk forms were permeable, some pervious, and impervious. Permeable sidewalk (Ps) can be classified into permeable block sidewalk, color porous ascone, decomposed granite rod tamping, sand pulling, grass protection block, coir net, and pebble paving. Some pervious sidewalk (SPs) was divided into clay floor brick, artificial granite block, processed landscape stone, solidified soil (dried), braille blocks for guiding the disabled, cube stone, disparate-shaped flagstone, consonant blocks, reinforced granite, and granite grass sidewalks, and was limited to those that did not have cement finishing between blocks. Impervious sidewalk (Is) was classified into artificial grass, rubber (urethane) chip, rubber floor, urethane, solidified soil (impervious), color porous ascone, concrete, piece-fixing braille blocks, and granite slab sidewalks. Ancillary buildings were classified into "other" and were calculated as impervious sidewalks in the final water balance analysis.

Living zone 1 comprises 60.6% of green area and 39.4% of sidewalk and artificial structure areas. Herbal plant space, such as grass, accounts for ~35.0% of the entire area, occupying a moderately large area, and the impervious sidewalk area is largely distributed, including small fitness facilities. Living zone 2 comprises 63.5% of green area and 36.5% of sidewalk and artificial structure areas. Living zone 3 comprises 69.5% of green area and 30.5% of sidewalk and artificial structure areas and living zone 4 comprises 79.4% of green area and 20.6% of artificial structure areas. Walking sphere 1 comprises 63.4% of green area and 36.6% of sidewalk and artificial structure areas, and walking sphere 2 comprises 65.7% of green area and 34.3% of sidewalk and artificial structure areas. Walking sphere 3 comprises 71.2% of green area and 28.8% of sidewalk area, and walking sphere 4 comprises 75.2% of green area and 24.8% of sidewalk and artificial structural areas. This result is similar to the greening rate of [108], which surveyed urban parks located in the metropolitan area of Korea. The urban parks' water balance analysis was conducted using the runoff coefficient according to the analyzed sidewalk forms.

3.4. Analyzing the Water Balance by Applying the Runoff Coefficient to Urban Park Land Cover Types

Before analyzing the water balance of the eight urban parks, their precipitation data were collected. The groundwater penetration regression equation and runoff coefficient calculated previously were applied to conduct the water balance analysis of the urban parks using the average value of three years in three places (Table A1).

Table 4 shows the precipitation data collected over three years at the Seoul, Paju, and Incheon meteorological stations. The meteorological data near the study region to be analyzed were used to average the precipitation patterns for the three years. Consequently, annual precipitation of 1071.82 mm was set, and the data were employed in the study sites to apply groundwater penetration, the runoff rate, etc.

Table 4. Results of evaluating the runoff rate per land use type of the study sites.

Site	Va	Ps	SPs	Is	Total
			mm/ha		
Life 1	159.26	18.60	177.93	205.11	560.91
Life 2	166.70	19.82	334.76	9.80	531.08
Life 3	170.69	0.00	333.00	29.34	533.03
Life 4	208.49	0.00	108.40	108.29	425.18
Walk 1	166.57	67.76	198.10	70.02	502.45
Walk 2	172.45	18.08	262.72	64.13	517.38
Walk 3	190.78	20.06	45.90	211.08	467.82
Walk 4	197.38	9.91	153.08	90.22	450.59
Average	179.04	19.28	201.74	98.50	498.56

The sidewalk form ratio for evaluating the water balance was proposed (Table 3) based on the status of the vegetation area, permeable sidewalk, and some pervious sidewalks investigated previously. The ratio of the impervious sidewalk area was proposed using the sum of sidewalk materials, such as concrete, asphalt, artificial grass, and other areas, such as ancillary buildings and fountains.

By using the average precipitation data of 1071.82 mm over three years in three places near the study sites, the runoff coefficient was applied according to land use, and the runoff rate was evaluated. Based on 1 ha, living zone 4 showed the lowest runoff with 425.18 mm, and living zone 1 had the largest with 560.91 mm. The average of the eight sites was 498.56 mm, indicating that 46.52% was leaked externally compared to the rainfall (Table 4).

The groundwater penetration was evaluated using the previously calculated regression equation for groundwater penetration per land use. By using the average rainfall data of 1071.82 mm over three years in three places near the study sites, the groundwater infiltration rate according to land use was evaluated. Based on 1 ha, living zone 4 had the highest recharge amount of 142.54 mm, and living zone 1 had a penetration of 112.75 mm, the smallest groundwater recharge. The average of the eight sites was 126.52 mm, indicating that 11.80% of the rainfall was recharged into groundwater (Table 5).

Table 5. Results of evaluating the infiltration rate per land use type of the study sites.

Site	Va	Ps	SPs	Is	Total
			mm		
Life 1	107.95	2.79	2.01	0.00	112.75
Life 2	112.99	2.97	3.79	0.00	119.75
Life 3	115.69	0.00	3.77	0.00	119.46
Life 4	141.31	0.00	1.23	0.00	142.54
Walk 1	112.90	10.15	2.24	0.00	125.29
Walk 2	116.89	2.71	2.97	0.00	122.57
Walk 3	129.31	3.00	0.52	0.00	132.83
Walk 4	133.79	1.48	1.73	0.00	137.00
Average	121.35	2.89	2.28	0.00	126.52

Based on the evaluated runoff and infiltration rates, the remaining precipitation can be calculated as evapotranspiration. The eight sites were found to have an average of 41.68% evaporation, from a range of 37.15–47.03% among the study sites (Table 6).

Table 6. Results of evaluating the water balance analysis of the study sites.

Site	Runoff		Infiltration Rate		Evapotranspiration	
	mm	(%)	mm	(%)	mm	(%)
Life 1	560.91	52.33	112.75	10.52	398.16	37.15
Life 2	531.08	49.55	119.75	11.17	420.99	39.28
Life 3	533.03	49.73	119.46	11.15	419.33	39.12
Life 4	425.18	39.67	142.54	13.30	504.10	47.03
Walk 1	502.45	46.88	125.29	11.69	444.08	41.43
Walk 2	517.38	48.27	122.57	11.44	431.87	40.29
Walk 3	467.82	43.65	132.83	12.39	471.17	43.96
Walk 4	450.59	42.04	137.00	12.78	484.23	45.18
Average	498.56	46.52	126.52	11.80	446.74	41.68

When calculating the amount by a unit of 1 ha based on the assessed runoff rate and penetration, 1 ha of urban park contributes an annual average of 1265.2 t to groundwater saving and 4467.4 t to atmospheric control. Therefore, 5732.6 t of water for rainfall of 1072.82 mm contributes to groundwater recharge and air control. When evaluating the penetration and evapotranspiration according to each study site area, walking sphere 2 (the biggest area) contributed 11,068.07 t to groundwater recharge and cultivated water resources that contributed to an atmospheric control of 38,997.86 t (Table 7).

Table 7. Results of evaluating the water resource recharge amount of the study site.

Site	Mount by 1 ha			Mount by Site Areas		
	Runoff	Evapotranspiration	Total	Infiltration	Evapotranspiration	Total
Life 1	1127.5	3981.6	5109.1	2435.40	8600.26	11,035.66
Life 2	1197.5	4209.9	5407.4	3508.68	12,335.01	15,843.68
Life 3	1194.6	4193.3	5387.9	1564.93	5493.22	7058.15
Life 4	1425.4	5041.0	6466.4	2351.91	8317.65	10,669.56
Walk 1	1252.9	4440.8	5693.7	6064.04	21,493.47	27,557.51
Walk 2	1225.7	4318.7	5544.4	11,068.07	38,997.86	50,065.93
Walk 3	1328.3	4711.7	6040.0	4011.47	14,229.33	18,240.80
Walk 4	1370.0	4842.3	6212.3	8274.80	29,247.49	37,522.29
Average	1265.2	4467.4	5732.6	4909.91	17,339.29	22,249.20

Table 8 shows the evaluation of the statistical relationships based on the assessed runoff rate, penetration data, and land use ratio of the study sites. The green space areas of urban parks were closely related to the runoff rate, penetration, and evapotranspiration, while the sum of the entire sidewalk area, excluding the vegetation area, showed the same statistical value. In other words, the statistical significance was secured for these facts: the larger the vegetation area, the more effective it is for groundwater recharge and increased evapotranspiration for atmospheric control (infiltration rate:green area ratio, $y = 0.6417x - 13.009$, $R^2 = 0.9345$); however, a smaller green area increases the runoff rate, whereas the penetration and evapotranspiration decrease (runoff rate:green area ratio, $y = -0.1383x + 137.13$, $R^2 = 0.9270$; evapotranspiration:green area ratio, $y = 0.1762x - 10.556$, $R^2 = 0.9246$). No statistical results were obtained for the permeable and impervious sidewalk areas in connection to the runoff, penetration, and evapotranspiration rates. Nevertheless, statistical significance confirmed that some pervious sidewalk increases the runoff rate and reduces the penetration and evapotranspiration rates when the area ratio is higher.

Table 8. Statistical analysis of the sidewalk forms influencing the water balance of urban parks.

Item		Regression Equation	Determination Coefficient (R^2)
Runoff rate	Green area ratio	$y = -0.1383x + 137.13$	0.9270
	Permeable sidewalk area ratio	$y = 2.5849x + 490.58$	0.0360
	Some pervious sidewalk area ratio	$y = 3.1108x + 437.76$	0.4476
	Impervious sidewalk area ratio	$y = -0.871x + 506.56$	0.0170
Infiltration rate	Green area ratio	$y = 0.6417x - 13.009$	0.9345
	Permeable sidewalk area ratio	$y = -0.6188x + 128.43$	0.0440
	Some pervious sidewalk area ratio	$y = -0.654x + 139.30$	0.4224
	Impervious sidewalk area ratio	$y = 0.1576x + 125.08$	0.0119
Evapotranspiration	Green area ratio	$y = 0.1762x - 10.556$	0.9246
	Permeable sidewalk area ratio	$y = -1.9662x + 452.81$	0.0339
	Some pervious sidewalk ratio	$y = -2.4568x + 494.76$	0.4545
	Impervious sidewalk area ratio	$y = 0.7134x + 440.19$	0.0185

When calculating the amount of 1 ha based on the evaluated runoff rate and penetration, 1 ha of urban park contributes an annual average of 1265.2 t to saving groundwater and 4467.4 t to atmospheric control (Table 7). In total, 5732.6 t of water for precipitation of 1072.82 mm contributes to groundwater recharge and air control.

Factors influencing groundwater recharge are soil texture, slope [109–111], and rainfall intensity [112,113]. However, this study excluded the slope and rainfall intensity. Additional tests must be conducted using this method.

Impervious sidewalks suppress groundwater recharge [114–116] and increase the external water runoff [117,118]. Reducing impervious areas can improve the water balance of urban parks. There are cases of removing impervious surfaces in Athens, Greece [119], Jian, China [120], and Seoul, Korea [121], to improve the hydrological cycle.

Rainwater detention ponds [122,123], gravel trenches [124,125], and storage trenches [126,127] can reduce the runoff speed of rainfall, increasing groundwater recharge and evapotranspiration [128,129]. Reducing rainfall runoff is effective for efficient water use [130,131]. The groundwater recharge effect of forests is a typical ecosystem service function [132], and urban parks have the same effect of recharging groundwater as forests [133].

4. Conclusions and Discussion

This study proposed urban parks as vital spaces to resolve various environmental and ecological issues in cities and improve the urban hydrological cycle. This study contributes to the continual urban park expansion by evaluating urban parks' water resource cultivation ability and urban hydrological cycle contribution by analyzing the water balance of parks in cities.

This study categorized the typical urban park land cover types into vegetation area, permeable sidewalk, some pervious sidewalk, and impervious sidewalk and measured the groundwater penetration of these land cover types. Vegetation area (Va) representing grass sidewalk had permeation of 214.51 mm compared to precipitation of 1194.4 mm; permeable block representing permeable sidewalk (Ps) had precipitation of 118.45 mm; clay blocks representing some pervious sidewalk (SPs) had precipitation of 10.43 mm; and no penetration was found in concrete representing impervious sidewalk (Is). The regression equations for the penetration of typical sidewalk materials of urban parks were calculated as follows: $y = 0.1648x + 1.3598$ for vegetation area (Va), $y = 0.0862x + 1.1899$ for permeable sidewalk (Ps), and $y = 0.0111x + 0.2157$ for some pervious sidewalk (SPs). The runoff coefficients were 0.245 for Va, 0.583 for Ps, 0.963 for SPs, and 1.000 for Is. The green area ratio of the eight urban parks was found to be approximately 68.2% on average. According to the soil environment analysis, sandy soil types with sand culture favorable to groundwater penetration and soil of a textural structure with a low rain–bed ratio were proposed for refinement.

For analyzing the study sites' water balance, the precipitation data of three years collected from nearby meteorological stations were averaged, and annual precipitation of 1071.82 mm was set. The water balance evaluated using the regression equations and the runoff coefficient calculated previously indicated that an average of 498.56 mm (46.52%) was leaked externally, and an average groundwater penetration of 126.52 mm (11.80%) was cultivated.

When calculating the amount of 1 ha based on the runoff and infiltration rates per evaluated land cover type, 1 ha of urban park saves an average of 1265.2 t of groundwater and contributes 4467.4 t to air control. Therefore, urban parks are vital spaces for improving the urban environment, as 5732.6 t water is contributed to groundwater recharge and air control with precipitation of 1072.82 mm. The assessed runoff rate, penetration data, and study sites' land use ratio statistical analysis showed that the green space area of urban parks is closely related to the runoff rate, infiltration rate, and evapotranspiration. Thus, reducing the sidewalk area is proposed. Waterways, wetlands, and gravel sidewalk materials are suggested to enhance urban parks' current water resource recharge functions. Creating only 1% of wetland or gravel sidewalks reduces the annual runoff rate by 10.32 mm, which is effective for urban parks' function of recharging water resources.

Therefore, urban parks can be evaluated as critical spaces for water resource recharge in cities. Hence, it is proposed that urban parks should be continuously expanded to cultivate groundwater and control the atmosphere in cities. Furthermore, it is proposed that more wetlands or gravel sidewalks should be created to direct green spaces within cities, significantly contributing to water resource recharge. Based on these outcomes, we look forward to expanding urban parks as a national level urban environment improvement project.

However, the experiment did not take into account the slope, rainfall intensity, soil texture, and season. Additionally, the experimental sites were only grass; therefore, the hydration from tree breathing was not considered. This is a limitation of this study. Thus, this study will have to be supplemented with further research.

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Appendix A

Table A1. Analysis of the data measuring the precipitation near the study sites.

Item	Seoul			Paju			Incheon			Average
	2016	2017	2018	2016	2017	2018	2016	2017	2018	
January	1.0	14.9	8.5	1.0	12.8	6.6	2.8	20.4	4.8	8.09
February	47.6	11.1	29.6	65.9	21.4	52.1	43.1	24.7	46.3	37.98
March	40.5	7.9	49.5	57.4	4.1	48.8	44.1	1.20	94.6	38.68
April	76.8	61.6	130.3	89.3	65.7	131.2	80.8	57.0	101.5	88.24
May	160.5	16.1	222	157.7	44.2	162.9	148.5	22.1	134	118.67
June	54.2	66.6	171.5	28.3	112.1	201.5	17.7	164.7	256.1	119.19
July	358.2	621	185.6	378.2	294.9	123.1	302.3	363	36.7	295.89
August	49.8	297	202.6	24.2	318	97.9	12.2	249.9	234.8	165.16
September	50.5	35	68.5	34.1	23.9	78.9	48.8	26.8	93.9	51.16
October	74.3	26.5	120.5	249.2	10.2	44.8	77.8	17.1	48.5	74.32
November	16.2	40.7	79.1	15.6	17	50.5	18.4	47.6	79	40.46
December	62.1	34.8	16.4	63.0	23.5	0	67.8	34.2	4.2	34.00
Total	991.70	1233.2	1284.1	1163.9	947.8	998.3	864.30	1028.7	1134.4	1071.8

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