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Estimation of stormwater interception ratio for evaluating LID facilities performance in Korea

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Abstract. To minimize the impact of urbanization, accurate performance evaluation of Low Impact Development (LID) facilities is needed. In Korea, the method designed to evaluate large-scale non-point pollution reduction facilities is being applied to LID facilities. However, it has been pointed out that this method is not suitable for evaluating the performance of relatively small-scale installed LID facilities. In this study, a new design formula was proposed based on the ratio of LID facility area and contributing drainage area, for estimating the Stormwater Interception Ratio (SIR) for LID facilities. The SIR was estimated for bio-retentions, infiltration trenches and vegetative swales, which are typical LID facilities, under various conditions through long-term stormwater simulation using the LID module of EPA SWMM. Based on the results of these numerical experiments, the new SIR formula for each LID facility was derived. The sensitivity of the proposed SIR formula to local rainfall properties and design variables is analysed. In addition, the SIR formula was compared with the existing design formula, the Rainfall Interception Ratio (RIR).

Keywords: EPA SWMM; low impact development; stormwater interception ratio

1. Introduction

Urban development means the expansion of impervious area, which affects hydrological cycle and urban environment. Changes of the natural hydrological cycle system by urbanization are accompanied by increased stormwater rate and volume, decreased infiltration, and decreased groundwater recharge and base flow (Ahiablame *et al*. 2012, Harbor 1994, Moscrip and Montgomery 1997, USGS 1999). To minimize the influence of urbanization and avoid the distortion of the hydrological cycle, stormwater should be actively managed.

In order to reduce the alteration of the hydrological cycle due to urbanization, Low Impact Development (LID) in the United States, Distributed Urban Design (DUD) in Germany, Water Sensitive Urban Design (WSUD) in Australia, and Sound Water Cycle on National Planning (SWCNP) in Japan have been implemented as stormwater management measures. The basic concept of these measures is to restore the hydrological cycle to a state which is similar to before urban development by reducing stormwater and delaying inflow rate to streams using distributed small-scale facilities (Coffman 2002, Han 2011). In Korea, the Law on Conservation of Water Quality and Aquatic Ecosystems was amended in 2006 to require the installation of non-point source pollution reduction facilities for development project of a certain scale or more. Recently, the concept of LID has been proposed as an economical and efficient stormwater and non-point source pollution management measure, and Korea Ministry of Environment is promoting the application of LID facilities through the Second Water Environment Management Basic Plan (2016-2025).

In order to achieve the purpose of installation of small-scale LID facilities and encourage the introduction of LID facilities, each facility has to be correctly assessed during the design phase (Lee *et al*. 2015). Since the Rainfall Interception Ratio (RIR) formula currently used in Korean Design and Evaluation Guidelines (NIER 2014) does not reflect the characteristics of each LID facility and is equally applied to all facilities, it has been reported that there are many problems in the design and evaluation of LID facilities (Choe *et al*. 2016). Also, since the current RIR formula was derived using the rainfall data of only four representative stations in Korea, it cannot be regarded as accurately reflecting the characteristics of various rainfall regions in Korea (Choi *et al*. 2014b). In addition, since the RIR formula is derived for large-scale facilities design, such as artificial wetlands or midsize or above reservoirs, it has been pointed out that application to the design and evaluation of relatively small-scale LID facilities is somewhat difficult (Choi *et al*. 2014a, Kim and Han 2010).

LID facilities do not handle rainfall directly, but rather process stormwater caused by rainfall. In order to evaluate these facilities, the ratio of the stormwater that can be

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intercepted by a LID facility among the total stormwater generated in a drainage area is important. Therefore, in this study, the term Stormwater Interception Ratio (SIR) was used for comparison with the existing RIR. A new SIR formula for the design and evaluation of LID facilities was proposed to improve the problems of the current RIR formula mentioned above. Environmental Protection Agency's Storm Water Management Model (EPA SWMM) including the standard LID facilities was constructed, and the SIR formula for each LID facility was derived through long-term continuous stormwater simulations. The sensitivity of the SIR formula to the local rainfall properties was analysed using rainfall data of 61 stations distributed throughout Korea, and the uncertainty of the SIR formula caused by local rainfall properties was investigated. In addition, the validity of estimation method of the proposed SIR formula as a function of the ratio of facility area and contributing drainage area (R_{fc}) was verified, through the sensitivity analysis of the SIR formula to the typical standard design variables of each LID facility. Finally, the existing RIR formula was compared with the proposed SIR formula.

2. Methods

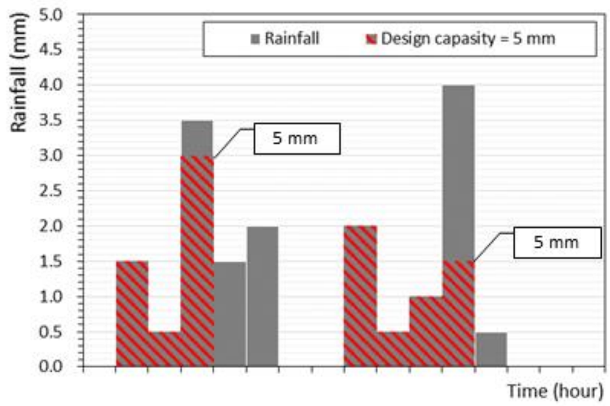
2.1 Currently applied rainfall interception ratio

The RIR formula applied to the design and evaluation of non-point source pollution reduction facilities for stormwater management in Korea is as follows:

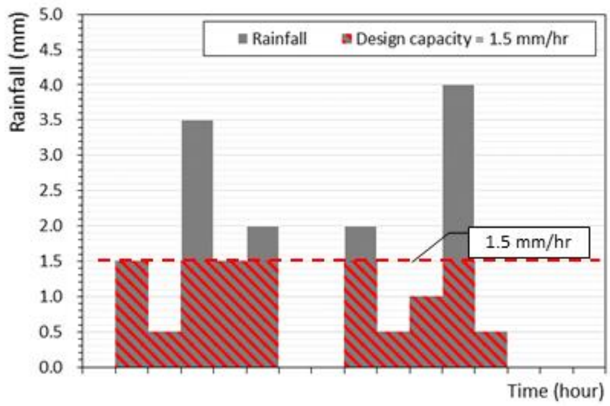
$$RIR = a \times 1\text{n}(P1) + b \quad (1)$$

where a and b are empirical constants. When designing and evaluating retention-based facilities, 0.2716 and -0.2425 are applied to a and b, respectively. On the other hand, when designing and evaluating flow-based facility, 0.2445 and 0.3174 are applied to a and b, respectively. The parameter $P1$ represents design capacity. In case of retention-based facilities, $P1$ is the rainfall depth (mm) corresponding to the design volume of the facility, and in case of flow-based facilities, $P1$ is the rainfall intensity (mm/hour) corresponding to the design flow of the facility (NEIR 2008). The flow-based facilities refer mainly to equipment-type facilities among non-point source pollution reduction facilities, so LID facilities such as small-scale bio-retentions, infiltration tranches, and vegetative swales covered in this study can be regarded as retention-based facilities.

The basic concept of design and evaluation using the RIR formula is shown in Fig. 1. If $P1$ = 5 mm is applied in the design of a retention-based facility [Fig. 1(a)], initial cumulative rainfall of up to 5 mm is intercepted by the facility in a rainfall event. Likewise, if $P1$ = 1.5 mm/hour is applied in the design of a flow-based facility [Fig. 1(b)], all rainfall less than 1.5 mm/hour in successive rainfall intensity time series is intercepted by the facility. The RIR calculated by Eq. (1) is defined as the ratio of the annual precipitation and the amount of precipitation that the facility can intercept.



(a) Retention-based facilities



(b) Flow-based facilities

Fig. 1 Basic concept explanation of rainfall interception ratio (NIER 2008)

2.2 Research procedure

The SIR of LID facilities is defined as the ratio of stormwater intercepted by the LID facility and stormwater occurring in the contributing drainage area. The amount of stormwater intercepted by the LID facility can be expressed as the difference between the average amount of annual stormwater generated from the contributing drainage area without LID facility (R_D, mm) and the average amount of annual stormwater generated from the contributing drainage area with LID facility (R_L, mm). Therefore, the equation for calculating SIR is as follows:

$$SIR = \frac{R_D - R_L}{R_D} \quad (2)$$

To propose the method for estimating the SIR formula for each LID facility using Eq. (2), the following research procedure was carried out:

- Construction of EPA SWMM in the study drainage area.
- Estimation of EPA SWMM parameters using EPA SWMM and Matlab linkage optimization module, and simulation of long-term stormwater with and without LID facility.
- Sensitivity analysis of the SIR to local rainfall

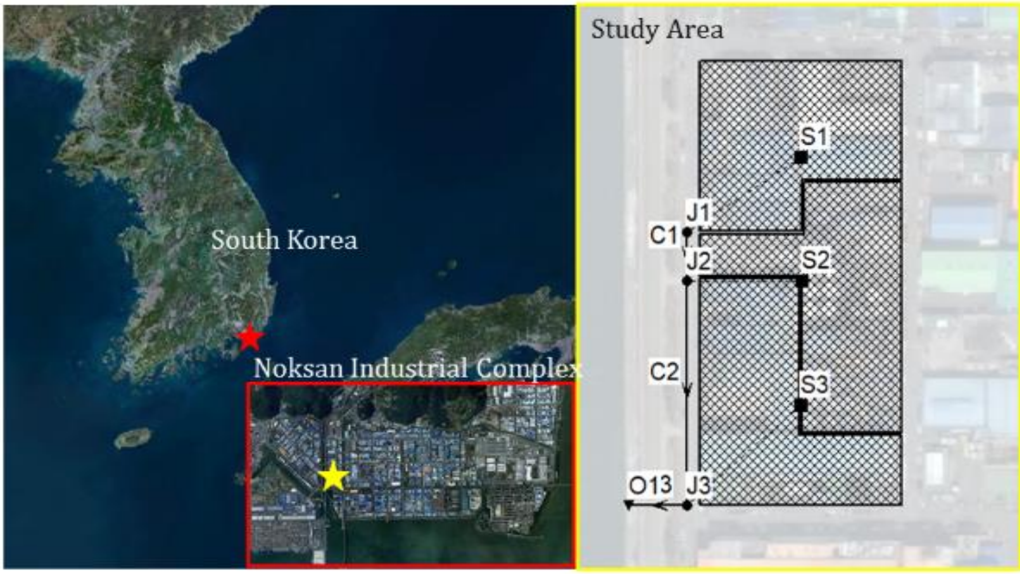


Fig. 2 Study area

properties using hourly rainfall data of 61 stations distributed throughout Korea.

- Sensitivity analysis of the SIR to standard design variables of LID facilities.
- Derivation of SIR formula as a function of R_{fc}, and comparison with currently applied RIR.

2.3 EPA SWMM construction

In this study, some area (13,000 m^2) of Noksan national industrial complex located in Busan, Southeast of Korea, where hourly rainfall data and stormwater data have been observed, were selected as the study area. The study catchment is impervious area consisting of asphalt and concrete pavements and steel buildings. EPA SWMM was constructed by dividing the study catchment into buildings and non-buildings, and all surface were set to 100 % impervious area. The location of the study catchment and subwatershed map of the constructed model are shown in Fig. 2, and the information of each subwatershed is shown in Table 1.

Hourly rainfall data from 2003 to 2013 from Busan station of Korea Meteorological Administration and the monthly average potential evapotranspiration calculated using Thornthwaite method were used as input data for the model to simulate stormwater. The simulated results of 2003 were excluded from our analysis to remove the effect of the initial condition.

2.4 EPA SWMM parameters estimation

To estimate the SIR using EPA SWMM, it is necessary to accurately simulate the stormwater in the study area. In general, the stormwater simulated by the model varies greatly depending on model parameters, and the reliability of results depends on the user's skill. In this study, EPA SWMM and Matlab linkage module was used to estimate SWMM parameters to improve the reliability of simulation results (Choe *et al*. 2015). The linkage module searches for

Table 1 Information of subwatershed

Subwatershed	S1	S2	S3
Land use/cover	Urban industrial / Asphalt and concrete		
Area (m^2)	4,212	4,719	4.069
Impervious (%)	100	100	100
Mannings N	0.013	0.013	0.013

optimal parameters using pattern search technique in Matlab, comparing the measured depth of stormwater with the simulated depth of stormwater.

The Kling-Gupta efficiency (KGE) proposed by Gupta *et al*. (2009) was applied to the objective function for performing the optimization process. The KGE considers mean, standard deviation, and correlation coefficient between observed data and corresponding simulated results, and was expressed as:

$$KGE = 1 - \sqrt{(\gamma - 1)^2 + (\alpha - 1)^2 + (\beta - 1)^2} \qquad (3)$$

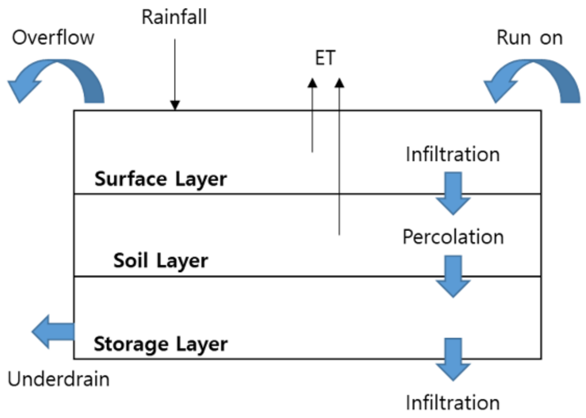
where γ is the correlation coefficient between observed and simulated data, α is a ratio of means of the observed and simulated data, and β is a ratio of standard deviations of the observed and simulated data.

The observed stormwater data used for estimating model parameters were measured for 20 rainfall events from April 2009 to July 2012 at the outlet point of the study area.

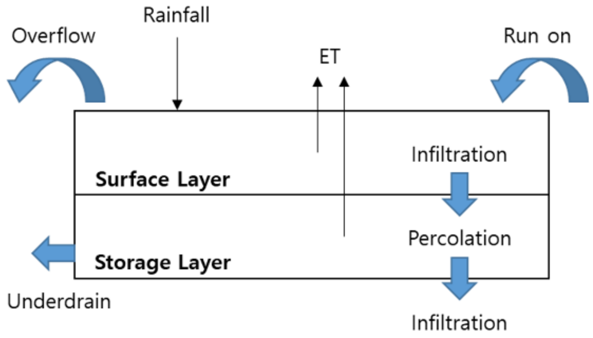
2.5 LID facilities design

EPA SWMM provides LID module to evaluate hydrological performance of LID facilities for urban watersheds. In this study, bio-retention, infiltration trench, and vegetative swale LID facilities were applied to the subwatershed S2, which is an area without buildings (see Fig. 2).

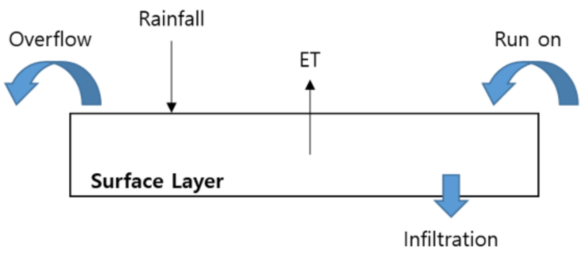
Bio-retentions consist of a surface, a soil, and a storage layer. Stormwater intercepted in the surface layer of bio-retention is evaporated into atmosphere or infiltrated into



(a) Bio-retention



(b) Infiltration trench



(c) Vegetative swale

Fig. 3 Conceptual diagram of LID facilities (U.S.EPA 2015)

the soil layer. Water infiltrated into the soil layer is evaporated again or percolated to the storage layer by gravity. Water reaching the storage layer is infiltrated into native soil and enters groundwater or is discharged through underground drainage facilities. Infiltration trenches consist of a surface layer and a storage layer. Stormwater flows into the surface of infiltration trenches to penetrate into the storage layer or to evaporate into atmosphere. Water stored in the storage layer is either infiltrated into native soil or discharged through underground drainage facilities. Vegetative swales consist of only a surface layer. Stormwater intercepted from side of the vegetative swale flows along the vegetative swale, being infiltrated into native soil or evaporated into atmosphere. The general conceptual diagram of each LID facility presented in U.S.EPA (2015) is shown in Fig. 3.

In general, 4% of the contributing drainage area is designed as facility area of a bio-retention, and the contributing drainage area, which is the area drained to the LID facility, is recommended from 500 to 4,000 m^2 (CVC 2012, DER 2001, KECO 2009, U.S.EPA 1999, VWRRC 2013). In this study, it is assumed that the contributing drainage area of 2,359.5 m^2, which is 50% of the subwatershed S2 (4,719 m^2), was set for a bio-retention, and that a bio-retention with a facility area of 94.38 m^2 is installed at the outlet of the contributing drainage area. Other bio-retention design variables were applied with reference to DOEE (2013), Palhegyi (2010), U.S.EPA (2015), and VWRRC (2013).

In the case of infiltration trenches, typically 3% of contributing drainage area is designed for facility area, and the contributing drainage area is suggested to be 2,000 m^2 (VWRRC 2013). Therefore, the contributing drainage area was set to 2,000 m^2 in the subwatershed S2, and an infiltration trench was installed with a facility area of 60 m^2 at the outlet of the corresponding contributing drainage area. Other infiltration trench design variables were applied to the values given in AWMS (2008), MC (2011), Palhegyi (2010), RC (2011), Tao *et al*. (2017), U.S.EPA (1999, 2015), and VWRRC (2013).

It is recommended that the facility area of vegetative swales be designed to 10% of the contributing drainage area, and the contributing area should be in the range of 4,000-8,000 m^2 (KECO 2009, PDEP 2006, TDEC 2015, U.S.EPA 2016). Therefore, the contributing drainage area was set to 4,719 m^2, which is the total area of the subwatershed S2, and a vegetative swale with a facility area of 471.9 m^2 was installed. Other vegetative swale design variables were applied with reference to ASCE (2001), CVC (2012), PDEP (2006), SOWP (2016), TDEC (2015), U.S.EPA (2015, 2016), and VWRRC (2013).

Table 2 summarizes the design specifications used for each facility. For more information on design variables, see U.S.EPA (2015).

In order to derive the SIR formula for the ratio of facility area and contribution area R_{fc}, a wide range of R_{fc} was applied. Considering the standard R_{fc} of each LID facility, the range of R_{fc} was set from 0.004 to 1 for bio-retentions and infiltration trenches, and from 0.03 to 1 for vegetative, respectively. Note that the standard values of R_{fc} of bio-retentions, infiltration trenches, and vegetative swales are 0.04, 0.03, and 0.1, respectively.

3. Results and discussion

3.1 Parameters estimation

The stormwater-related parameters of EPA SWMM used for the optimization process are %Slope, N-Imperv, Dstore-Imperv and %Zero-Imperv of each subwatersed. The results of parameter estimation are shown in Table 3. The simulated stormwater using estimated parameters and the observed stormwater are shown in Fig. 4. The coefficient of determination (R^2) and the Nash-Sutclffe Efficiency coefficient (NSE) are 0.98 and 0.93, respectively, so the stormwater is simulated appropriately.

Table 2 Major design variables for LID facilities

LID type		Parameter	Value	Unit
Bio-retention	Area	Contributing drainage area	2,359.5	m^2
		Percent of facility area	4	%
	Surface	Berm Height	300	mm
		Vegetation Volume Fraction	0	-
		Surface Roughness	0	-
		Surface Slope	0	%
	Soil	Thickness	600	mm
		Porosity	0.45	-
		Field Capacity (volume fraction)	0.30	-
		Wilting Point (volume fraction)	0.15	-
		Conductivity	50	mm/hour
		Conductivity Slope	46.9	-
		Suction Head	61.3	mm
	Storage	Thickness	300	mm
		Void Ratio (Voids/Solids)	0.625	-
		Seepage Rate	4	mm/hour
		Clogging Factor	0	-
	Drain	Coefficient	0.23094	-
		Exponent	0.5	-
		Offset Height	300	mm
Infiltration Trench	Area	Contributing drainage area	2,000	m^2
		Percent of Facility Area	3	%
	Surface	Berm Height	0	mm
		Vegetation Volume Fraction	0	-
		Surface Roughness	0.24	-
		Surface Slope	0.5	%
	Storage	Thickness	1,500	mm
		Void Ratio (Voids/Solids)	0.4	-
		Seepage Rate	4	mm/hour
		Clogging Factor	0	-
	Drain	Coefficient	0.23094	-
		Exponent	0.5	-
		Offset Height	300	mm
Vegetative swale	Area	Contributing drainage area	4,719	m2
		Percent of Facility Area	10	%
	Surface	Berm Height	400	mm
		Vegetation Volume Fraction	0.15	-
		Surface Roughness	0.2	-
		Surface Slope	3	%
		Swale Side Slope	3	-

Table 3 Stormwater parameters calibration

Subwatershed	S1	S2	S3
% Slope	0.01	0.01	0.01
N-Imperv	0.024	0.024	0.024
Dstore-Imperv	2.5356	2.5356	2.5356
%Zero-Imperv	0.0156	0	0

3.2 Effect of local rainfall on stormwater interception ratio

Rainfall properties such as annual rainfall, seasonality, frequency of occurrence of rainfall events, the number of rain days vary from region to region. The local rainfall properties affect stormwater processes in urban areas and

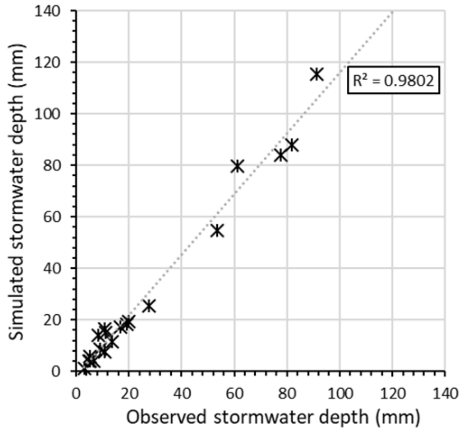


Fig. 4 Stormwater calibration results

also affect the amount of stormwater intercepted by LID facilities. In this study, the effect of local rainfall properties on SIR of the LID facility was analyzed.

The stormwater simulation was performed by inputting various local rainfall data to the same drainage area using the pre-constructed EPA SWMM. From this, the SIR with respect to local rainfall data was calculated. The hourly rainfall data from 2003 to 2013 at 61 stations of Korea Meteorological Administration were used as input local rainfall data. The location of observation stations is shown in Fig. 5.

Fig. 6 shows the results of the SIR calculated from stormwater simulated by using local rainfall data and various R_{fc}'s of the LID facility. As shown in Fig. 6(a), the SIR of the bio-retention is estimated from 0.443 (using rainfall data at the Namhae station) to 0.635 (using rainfall data at the Ulleungdo station) when the R_{fc} of 0.04 was applied. It can be seen that the SIR varies by a maximum of about 0.2 depending on local rainfall properties. Likewise, the SIR of the infiltration trench and the vegetative swale shown in Fig. 6(b) and (c) has a difference of up to about 0.2 depending on local rainfall properties when they designed with the standard R_{fc} (i.e., 0.03 for infiltration trench and 0.10 for vegetative swale). As local rainfall properties have a significant influence on the SIR, it should be noted that an error of up to 0.1 may be included in the case of applying a single SIR formula to the whole of Korea. Therefore, it is considered that such an error needs to be reflected in the design criteria.

3.3 Effect of LID design variables on stormwater interception ratio

Since the design specifications of the LID facility affect the amount of stormwater that is intercepted by the LID facility, the effect of the design specifications of the LID facility on the SIR should be analyzed. Since the proposed SIR formula is expressed as a function of the R_{fc} based on the standard design specification of the LID facility, it is necessary to examine the sensitivity of the SIR to the LID facility installed differently from the standard design specification.

Among the design specifications of the LID facility, the

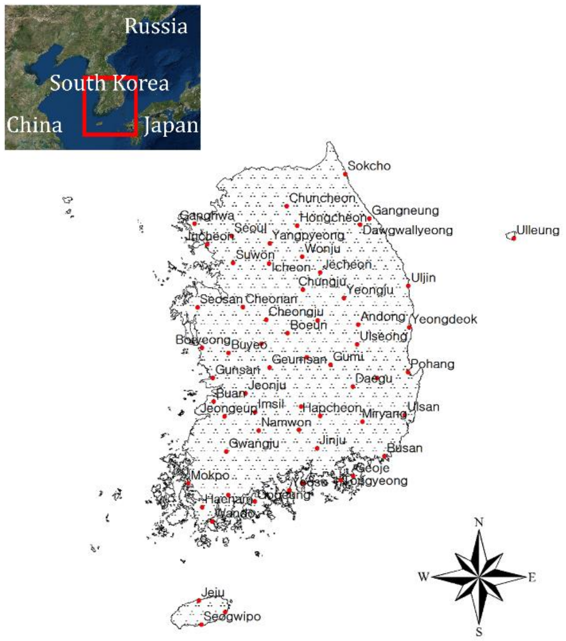
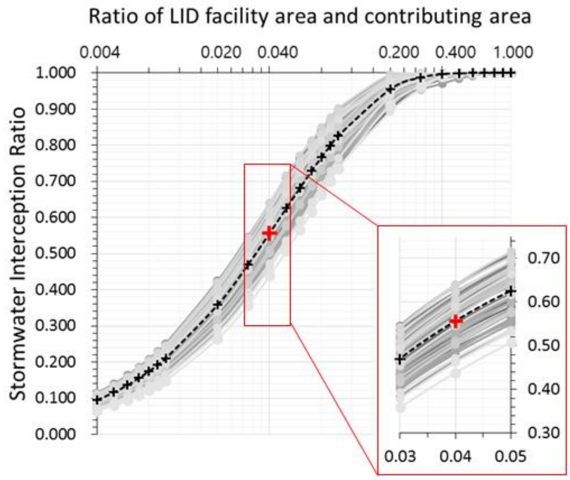


Fig. 5 Location of precipitation stations

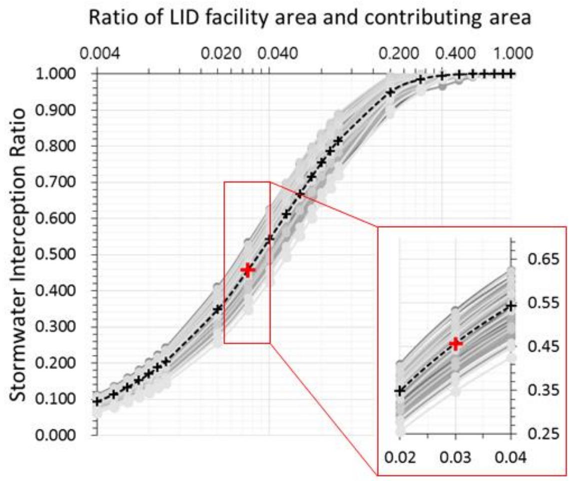
design specifications that have the greatest influence on the interception of stormwater are the depth of each layer. As shown in Table 4, the stormwater was simulated by varying the design depth of each layer of the LID facility, and the corresponding SIR was calculated for each case. The changes of the SIR with respect to the change of the depth were examined by using local rainfall data of the 9 major stations such as Seoul, Incheon, Busan, Gangneung, Gwangju, and so on (see Fig. 7). When the SIR empirical formula is proposed as a standard guideline, all of the precipitation data at 61 meteorological stations throughout Korea were used in order to obtain representativeness. However, in order to analyze the sensitivity of the design specifications of the LID facility for SIR, it was considered sufficient to use precipitation data only for the 9 major meteorological sites. The R_{fc} for each facility was fixed to standard value (0.04 for bio-retention, 0.03 for infiltration trench, and 0.1 for vegetative swale).

As can be seen in Fig. 7(a), the SIR was increased by a maximum of about 0.044 when the depth of surface layer of bio-retention was increased by 100 mm. When the depths of the soil layer and the storage layer were increased by 100 mm, the corresponding SIR was increased by about 0.007 and 0.015, respectively [Fig. 7(b) and (c)]. As shown in Fig. 7(d), the SIR was increased by about 0.015 when the depth of storage layer of infiltration trench was increased by 100 mm. For the vegetative swale in Fig. 7(e), the SIR was increased by about 0.006 when the depth of surface layer was increased by 100 mm.

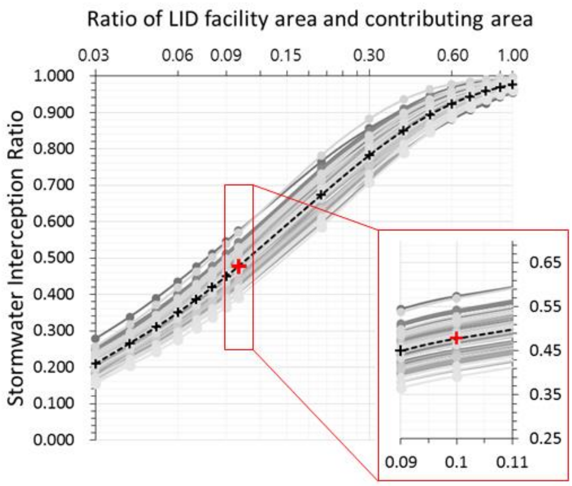
It means that the increase in the SIR is less than 0.05 even if the surface depth of the bio-retention, which has the largest variation of the SIR, is increased by 100 mm (i.e., the depth of entire surface layer is 400 mm). It is practically not feasible to design the surface layer of the bio-retention of 400 mm or more. The influence of changes in design significations of LID facilities within the actual application



(a) Bio-retention



(b) Infiltration trench



(c) Vegetative swale

Fig. 6 Stormwater interception ratio with various local rainfall properties

range will be relatively small compared to local rainfall properties. Therefore, even if the SIR formula is derived as a function of the R_{fc} with standard design specifications, there will be no major problem in practice.

Table 4 Design depth of each layer used in sensitivity analysis

Case	LID type	Design depth (mm)		
		Surface layer	Soil layer	Storage layer
Case A	Bio-retention	200 to 400	600	300
Case B	Bio-retention	300	500 to 700	300
Case C	Bio-retention	300	600	200 to 400
Case D	Infiltration trench	-	-	1,300 to 1,700
Case E	Vegetative Swale	300 to 500	-	-

3.4 Stormwater interception ratio formula

The SIR estimated form local rainfall data at 61 stations provided by Korea Meteorological Agency was averaged, and the SIR formula based on the ratio of facility area and contributing drainage area was proposed as follows:

$$SIR = c \times 1\text{n}(R_{fc}) + d \tag{4}$$

where, R_{fc} is the ratio of facility area and contributing drainage area of LID facility, c and d are empirical constants given by the LID facility. If the empirical constants of Eq. (4) are determined taking into account the full range of the R_{fc}, the results that do not fit the reality will be derived due to extreme R_{fc}'s that are not practically acceptable. As shown in Fig. 6, in the cases of bio-retention and infiltration trench, the SIR converges to 1 regardless of local rainfall properties when the R_{fc} is 0.2 or more. So the empirical constants of the SIR formula were derived in the range of the R_{fc} between 0.004 and 0.2. However, since the SIR of vegetative swale do not converge to 1, the empirical constants was derived in the range of the R_{fc} between 0.03 and 1.0. The derived empirical constants for each LID facility are shown in Table 5.

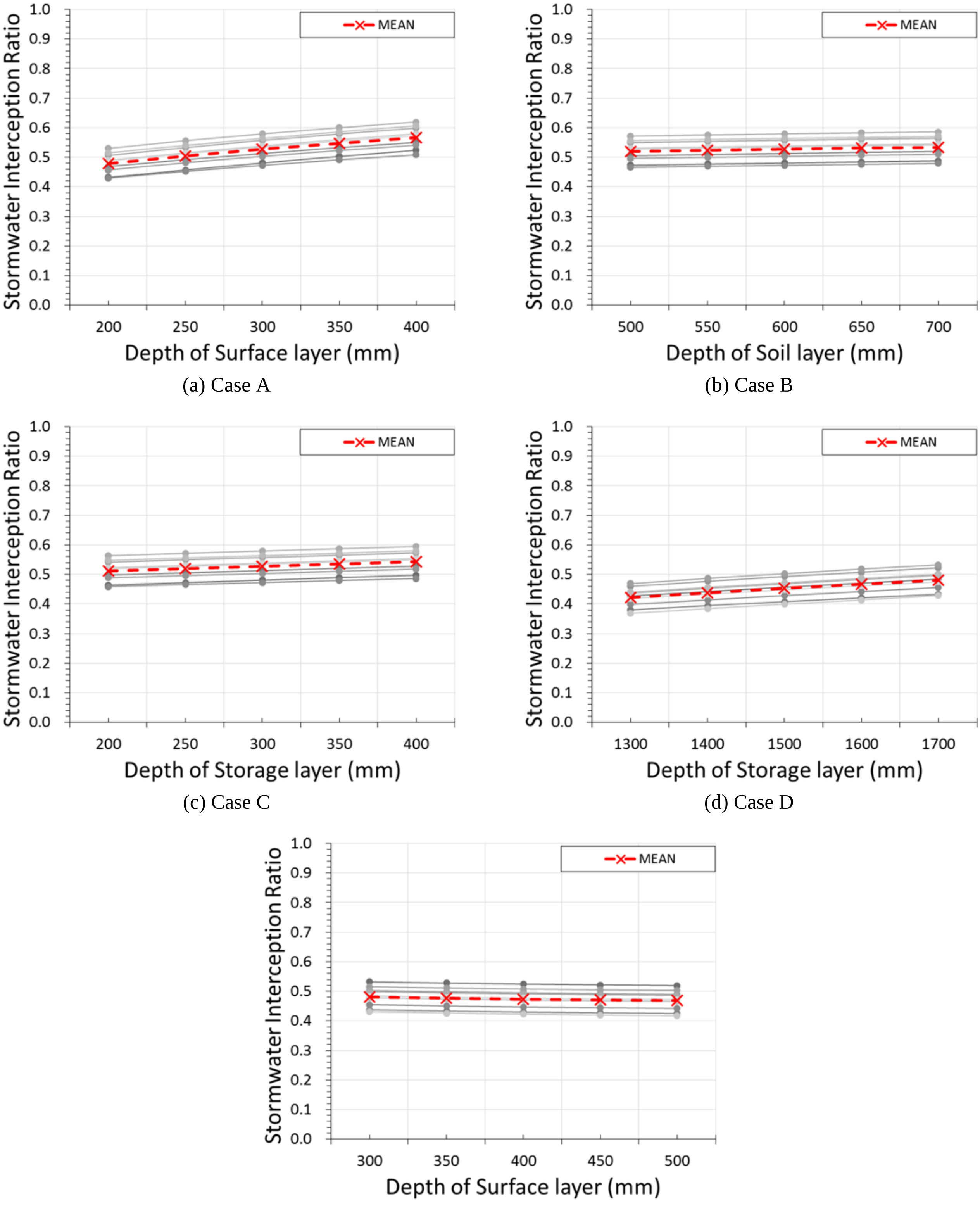
The SIR that is proposed as a function of the R_{fc} was compared with the existing RIR. Since the existing RIR is expressed as a function of the design capacity of the facility, the SIR expressed as a function of the R_{fc} was converted into a function of the design capacity as follows:

$$P1 = \frac{WQ_v}{A \times 10} \tag{5}$$

where, WQ_v is design volume (m^3), which can be calculated from the standard design specifications of the LID facility. And A is contributing drainage area (ha).

Table 5 Empirical constants for the SIR formula for each LID facility

LID type	c	d
Bio-retention	0.2387	1.3462
Infiltration Trench	0.2361	1.3281
Vegetative Swale	0.2351	1.0255



(a) Case A

(b) Case B

(c) Case C

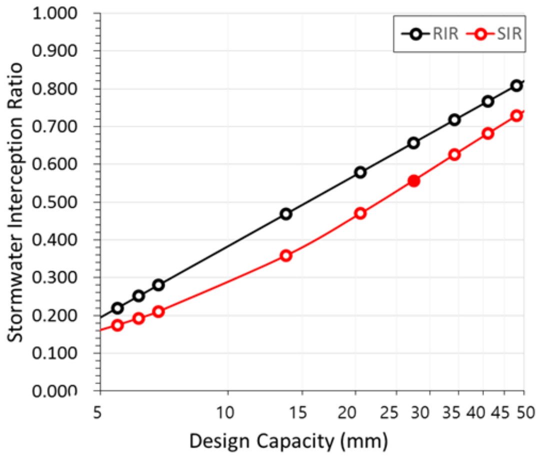
(d) Case D

(e) Case E

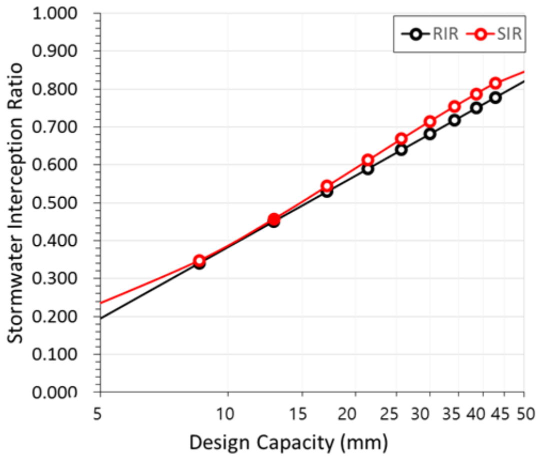
Fig. 7 Stormwater interception ratio with various LID design variables

Since the design capacity of the existing RIR formula should be 5 mm or more, the SIR and RIR were compared in the range of the design capacity of 5 mm or more (Fig. 8). However, in the case of the vegetative swale, the design capacity of about 7 mm is calculated even when the minimum R_{fc} of 0.03, so the comparison between the SIR and RIR was carried out in the design capacity of 7 mm or more.

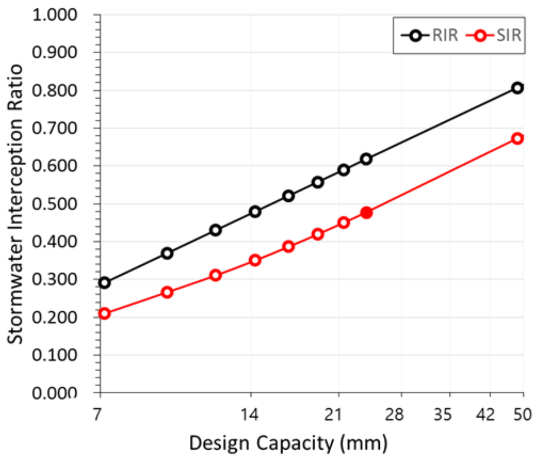
As shown in Fig. 8(a) and (c), in the case of bio-retentions and vegetative swales, the amount of intercepted



(a) Bio-retention



(b) Infiltration trench



(c) Vegetative swale

Fig. 8 Comparison of RIR and SIR

stormwater calculated from the proposed SIR was smaller than that calculated from the current applied RIR. In contrast, as can be seen in Fig. 8(b), the amount of intercepted stormwater calculated from the SIR of the infiltration trench was estimated to be higher than that calculated from the RIR. It means that the existing RIR overestimates the performance of the bio-retention and the vegetative swale, and underestimates the performance of the infiltration trench. Considering that the error of the SIR due to the difference in local rainfall characteristics may by up to 0.1(see Fig. 6), it can be recognized that the RIR currently in use may overestimate the performance of bio-retentions and vegetative swales beyond the practically allowable error range.

4. Conclusions

The RIR formula currently used in the design and evaluation of non-point pollution reduction facilities for stormwater management practice in the Republic of Korea has been reported to be inadequate for the design and evaluation of small-scale LID facilities. In addition, there is a limitation that various rainfall properties in each region were not reflected when the RIR formula was derived. Therefore, in this study, the new SIR formula for design and evaluation of bio-retentions, infiltration trenches, and vegetative swales among LID facilities was proposed.

As the proposed SIR formula has a maximum uncertainty of about 0.1 depending on local rainfall properties, it would be desirable to construct local SIR formulas that can reflect local rainfall properties rather than applying a single SIR formula to the whole Korea for designing and evaluating accurately LID facilities.

As results of the sensitivity analysis of the proposed SIR formula to the design variables of the LID facility, it can be seen that it does not have a significant effect on the estimation result of SIR even if some standard design specifications are changed in realistic construction range. In other words, it is more effective to increase the area of the facility than to increase the depth of each layer of LID facilities when more stormwater needs to be intercepted. These results also indicate that it is more reasonable to derive the SIR formula as a function of the R_{fc} than the design capacity of the LID facility.

From the comparison of the proposed SIR and existing RIR, it can be recognized that the RIR overestimates the performance of bio-retention and vegetative swale over the practically allowable error range, and underestimates slightly the performance of infiltration trench.

However, since the SIR formula proposed in this study is not applicable to the LID facilities where facility area and contributing drainage area are the same, such as green roof and permeable pavement, further research should be needed.

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