International Journal of Hybrid Information Technology
Vol. 9, No.9 (2016), pp. 411-422
http://dx.doi.org/10.14257/ijhit.2016.9.9.37

Application of Benefit Assessment to Infiltration Storage Tank and Permeable Pavement Demonstrated in Seoul Metropolitan, Korea

Seung Won Lee[1] and Reeho Kim[2*]

[1,2]Environmental and Plant Engineering Research Institute, Korea Institute of Civil Engineering and Building Technology, 283, Goyangdae-Ro, Ilsanseo-Gu, Goyang-Si, Geonggi-Do, 10223, Republic of Korea
[1]seungwonlee@kict.re.kr, [2]rhkim@kict.re.kr*

Abstract

Seoul metropolitan has established a vision as 'Healthy water-cycle city' to restore urban water-environmental as natural water-cycle. Therefore, various infiltrative Low Impact Development (LID) facilities are constructed and operated, however, benefit analytic plans for systematic valuation are insufficient. In this study, to analyze various benefits of these kinds of infiltration facilities, contents for benefit analysis were selected and categorized. As a result of quantification and valuation, infiltration storage tank and permeable pavement showed the total benefit as 0.99 dollar/yr·m^2 for infiltration storage tank and 1.10 dollar/yr·m^2 for infiltration storage tank. Characteristics of benefit distribution were various reflecting characteristics of each infiltration facility (Wastewater treatment saving: 88~90%, Energy saving: 4%, Air quality improvement: <1%, Climate change adaptation: 5~7%, Respiratory health care: <1%). As further studies, the synergy effects by integrated LID systems would be evaluated such as prevention of heat island based on suggested benefit assessment plans for each LID facility

***Keywords**: Low Impact Development (LID), Benefit assessment, Quantification and valuation, Infiltration storage tank, Permeable pavement*

1. Introduction

In most of cities, as impermeable area was increased dramatically since there urbanization, the amount of rainfall run-off was also increased and the amount of evapotranspiration was decreased due to the decreased green and permeable area. Especially, climate change increases ambient temperature and the differences among annual rainfall events, and then it causes frequent flood events which current gray infrastructure cannot be affordable. Therefore, restoring to healthy water cycle is needed to shift urban design paradigm as current gray infrastructure to green infrastructure considering Low Impact Development concept.

Low Impact Development (LID) means the decentralized network for effective rainfall management such as green roof, infiltration storage and permeable pavement. These kinds of LID facilities have important roles for reduction of surface run-off and improvement of water environment by rainfall run-off storage and its infiltration functions [1]. Especially, the LID means the developing concept to manage rainfall and run-off as possible in the rainfall area to maintain and restore to hydrological characteristics which were displayed before the development. And they also could contribute to cause positive effects such as not only reduction of non-point pollutants but also energy saving, air quality improvement, carbon reduction and real-estate value increasing [2].

[*] Corresponding Author

ISSN: 1738-9968 IJHIT

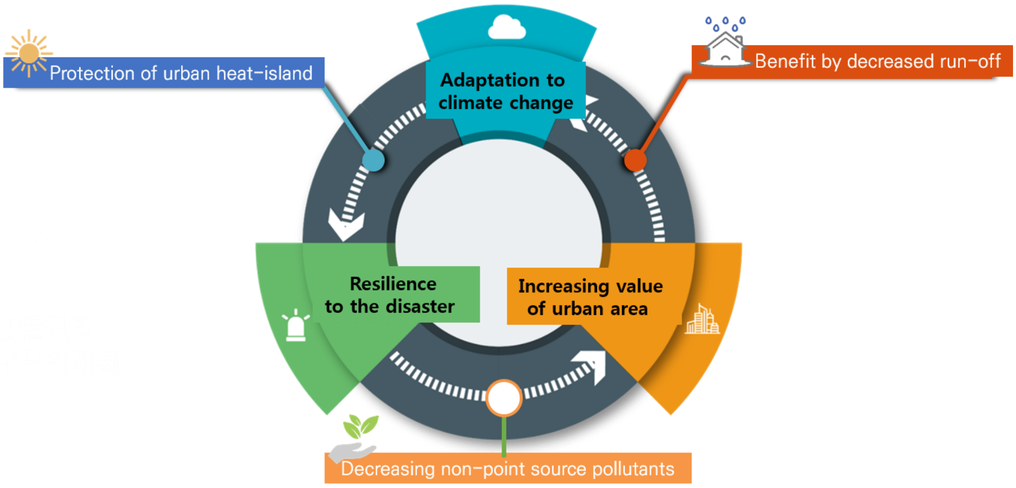


Figure 1. Conceptual Diagram for Contributions of LID to Urban Area

Recently, it is analyzed that the economic values of LID facilities are high, but the various researches are also needed for improvement of assessment to LID facilities. For example, USEPA compared and suggested the construction costs of LID facilities to residential complex, however the study did not deal with functional characteristics of the LID facilities [3]. And although the other researches also displayed the beneficial assessment of LID facilities, the results were such as a fragmentary benefit of unit LID facility and the integrated considerations are insufficient to estimate accumulated benefits of LID facilities [4]. In this study, two-step framework was applied to infiltrative LID facilities such as infiltration storage tank and permeable pavement constructed in Seoul Metropolitan in Korea and the beneficial values were analyzed by quantification and valuation.

2. Methodology

2.1. Study Area

Table 1 displays abstraction of infiltration facilities for analysis of their beneficial characteristics which facilities have been demonstrated in Seoul Metropolitan, Korea. Infiltration storage system is for transportation facilities such as parking lot, and for this study, an infiltration storage system constructed underground of public parking lot in Jongno-gu, Seoul. Rainfall on surface of the public parking lot flows by slope and flows into the infiltration storage tank. And the infiltration storage tank has infiltration function to increase possible volume for rainwater management, and artificial electricity for drainage could be replaced by natural recovery function comparing custom storage tank. In the case of the infiltration storage tank for this research, ideal catchment area of the public parking lot is over 2,000 m^2 to collect surface rainfall run-off, however, the effective catchment area would be the half of the entire catchment area due to the structural problem of the public parking lot. Therefore, in this research, beneficial characteristics were analyzed assuming that the catchment area for infiltration storage facility is 1,000 m^2.

Table 1. Summarized Specification of Demonstrated LID Facilities for Benefit Assessment

	Infiltration storage tank	Permeable pavement
Catchment area	1,000 m^2	62.7 m^2
Location	Jongno-gu, Seoul	Dobong-gu, Seoul
Classification of applied facility	Parking lot	Transportation
Unit value for construction	560.71 *USD/m^2	4.36 USD/m^2
Annual operating cost	872.52 USD	497.34 USD

* USD: US dollar

Permeable pavement is a kind of LID facilities for improvement of permeability of road and sidewalk. And permeable pavement could also contribute to decrease environmental problems such as ground-water level lowering, urban flood events and urban heat-island phenomena. Especially, Seoul metropolitan promote extension of permeable pavement to sidewalk as their policies as shown in Figure 2. Entire sidewalks area in Seoul Metropolitan is over 6,000,000 m^2 and approximate 3% of sidewalks are permeable pavement currently. Seoul Metropolitan has plans to transform impermeable sidewalks to permeable pavement substantially until 2025. In this research, beneficial characteristics for permeable pavement were analyzed which was constructed in Dobong-gu, Seoul.

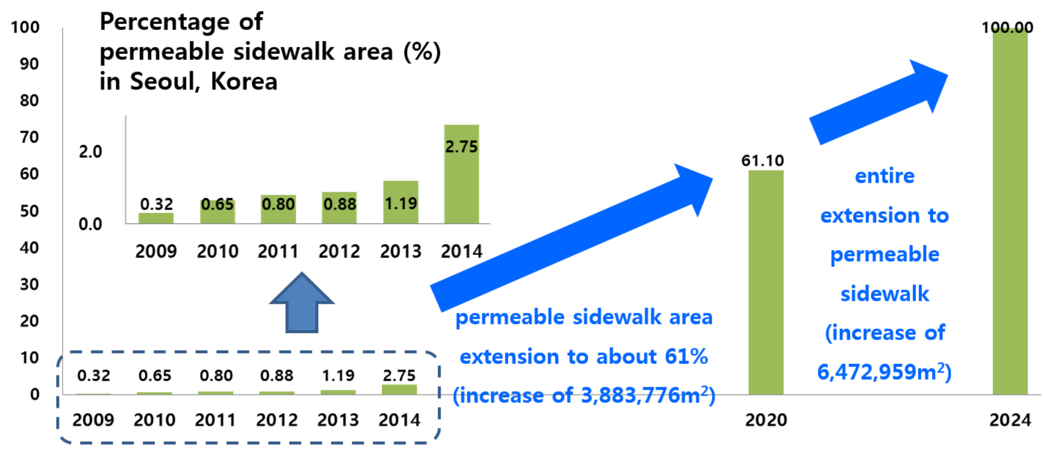


Figure 2. Plans for Extension of Permeable Pavement in Seoul, Korea

2.2. Benefit Assessment

In this study, benefit analysis was applied to the infiltration storage tank and permeable pavement to quantify the beneficial effects and assess their potential values for rainfall management. For the benefit analysis, contents for the benefit analysis were categorized as wastewater treatment saving, energy saving, air quality improvement, climate change adaptation and respiratory health care. And each category was quantified in the first step and assessed in the second step as shown in Table 2.

Table 2. Categorized Benefit Analysis

Categories	The first step (Quantification)	The second step (Valuation)
Wastewater Treatment Saving	Runoff reduction volume (m^3) = [Rainfall (mm) × *GI Area (m^2) × Runoff reduction rate (%)] / 100,000(mm/m)	Annual decreased cost for wastewater treatment (USD) = Runoff reduction volume (m^3) × Unit cost for wastewater treatment (USD/m^3)
Energy Saving	Annual decreased gas energy for heating (MJ) = Annual warming degree days (°C·day) × 24 hr/day × ΔU × GI Area (m^2) Annual decreased electricity for cooling (kWh) = Annual cooling degree days (°C·day) × 24 hr/day × ΔU × GI Area (m^2)	Annual decreased natural gas cost for warming (USD) = Annual decreased gas energy for heating (MJ) × Unit cost for natural gas energy (USD/MJ) Annual decreased electricity cost for cooling (USD) = Annual decreased electricity for cooling (kWh) × Unit cost for electricity energy (USD/kWh)
Air Quality Improvement	Annual air pollutants reduction (kg) = Air pollutants reduction for unit area(kg/m^2) × GI Area (m^2) (ex) NO_2: 0.00146 kg/m^2 (Currie and Bass, 2008)	Annual estimated benefit for air pollutants reduction (USD) = Annual air pollutants reduction (kg) × Estimated benefit for unit reduction of air pollutants (USD/kg)
Climate Change Adaptation	Annual carbon reduction (kg C) = Carbon reduction for unit area (kg C/m^2) × GI Area (m^2) (0.2 kg C/m^2, Gettert, *et al*., 2009)	Annual estimated benefit for carbon reduction (USD) = Annual carbon reduction (kg C) x Estimated benefit for unit reduction of carbon (USD/kg C)

* GI: Green Infrastructure such as LID facilities

Based on the categorized benefit analysis in Table 2, this study applied Triple Bottom Line (TBL) method to LID valuation. TBL means assessment to consider not only direct economic effects by specific facility or project but also its direct and indirect environmental and social effects. It is principal to consider economical management of the facility, stable environment and sustainable society, then it also has an object to realize sustainable development in environment area.

Applying TBL analysis to LID facilities, initial construction and operation cost for the facility could be used to analyze economic effects of the LID facility. And TBL analysis also directly and indirectly evaluate environmental effects such as avoiding wastewater treatment load, energy saving and air quality improvement. And social benefit like climate change adaptation through carbon reduction could be assessed directly and indirectly quantified and valuated applying TBL analysis concept.

This study utilized two-step framework to estimate economic, environmental and social benefits and analyze these benefits. The two-step framework was developed by Center for Neighborhood Technology (CNT) and was applied to Chicago city in USA [2]. The applied framework is designed to assess accumulated benefits of infiltration facilities considering various benefit categories including wastewater treatment saving, energy saving, air quality improvement, climate change adaptation and respiratory health care.

As shown in the Figure 3, the first step of framework is to define the units of benefit contents and quantify them. And the second step is to determine beneficial values based on quantification at the first step. Additionally, the indirect benefits were also considered through two-step framework which were caused by direct benefits in the other categories [5,6].

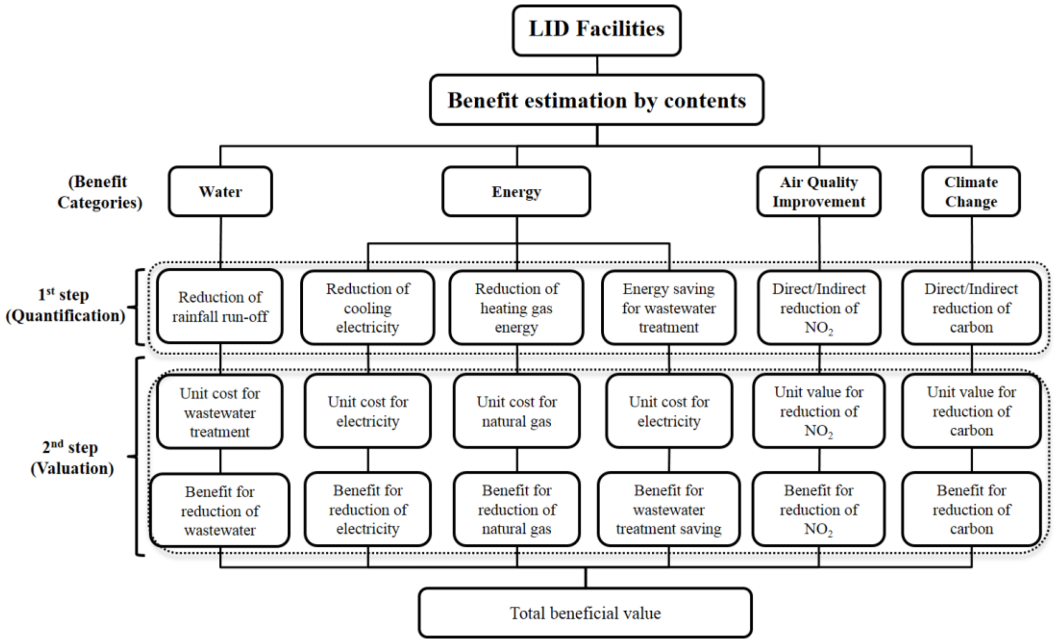


Figure 3. Two-Step Framework of Benefit Analysis for LID Facilities

3. Results and Conclusion

3.1. Structure of Basic Units for Benefit Assessment

For the analysis of categorized benefits for infiltration facilities, the necessary information were arranged (Table 3) and they were used for the assessment. Unit cost for wastewater treatment and annual precipitation during 10 years were used for the estimation of benefit with respect to wastewater treatment saving, and the related information such as unit costs for electricity are specified for Seoul Metropolitan in Korea [6]. Run-off reduction rate of each infiltration facility was assumed that the LID facility should treat 90 percentile of each rainfall event. Considering the assumption and specific conditional characteristics of facilities, the reduction rates were estimated as 92.0% for infiltration storage tank and 93.6% for permeable pavement.

Beneficial effects of energy saving for infiltration storage tank and permeable pavement were estimated with respect to decreased electricity cost for wastewater treatment according to decreased wastewater loads to wastewater treatment plants. And the decreased electricity consumption was related to indirect beneficial effects for air quality improvement and climate change adaptation. Because decreased electricity consumption by LID facilities could be assumed and quantified as decreased electricity production using fossil fuel, and reduction of air pollutant and carbon could be also quantified and valuated indirectly based on the reduction of electricity production load.

For the estimation of benefit by air quality improvement, NO_2 and SO_2 reduction by an infiltration facility and its unit cost data were applied [7,8]. And social benefits by carbon reduction was also analyzed based on the data such as carbon reduction load and its unit cost. With respect to respiratory health care, estimated benefit data for reduction of respiratory diseases caused by NO_2 and SO_2 were used [9]. Additionally, indirect benefits by water and energy saving were estimated using related quantification data.

Table 3. Basic Unit Information for Annual Estimated Benefit through Infiltration Facilities

Category	Benefit Content	Estimation	Unit	Ref.
Water saving	Unit cost for wastewater treatment	0.64	dollar/m^3	[6]
	Annual precipitation during 10 years	1,511.5	Mm	[6]
Energy saving	Unit cost for electricity energy	0.09	dollar/kWh	[6]
	Decreased energy for wastewater treatment for unit volume	0.314	kWh/m^3	[6]
Air quality improvement	Estimated benefit for unit reduction of NO_2	7.36	dollar/kg	[6]
	NO_2 reduction coefficient by energy saving	0.000879	kg/kWh	[6]
	Estimated benefit for unit reduction of SO_2	4.54	dollar/kg	[7]
	SO_2 reduction coefficient by energy saving	0.002385	kg/kWh	[8]
Climate change adaptation	Estimated benefit for unit reduction of carbon	0.19	dollar/kg C	[6]
	Carbon reduction coefficient by energy saving	0.89	kg C/kWh	[6]
Respiratory health care	Estimated benefit for reduction of respiratory diseases caused by NO_2	0.91	dollar/kg	[9]
	Estimated benefit for reduction of respiratory diseases caused by SO_2	1.67	dollar/kg	[9]

3.2. Characteristics of Benefit Variation of Infiltration Facilities

Figure 4 displays annual beneficial effects for infiltration storage tank. In the case of infiltration storage tank, annual decreased cost for wastewater treatment has the greatest portion as 90%. Because, infiltration storage tank is constructed underground a public parking lot and, due to this kind of structural characteristics, the other direct beneficial effects were not estimated. Additionally, there is not vegetated area for infiltration storage tank, therefore, only indirect benefit by decreased electricity consumption for wastewater treatment was estimated for air quality improvement category and climate change adaptation category. Decreased cost for wastewater treatment per unit area (0.8824 US dollar/yr·m^2) and decreased electricity cost for wastewater treatment per unit area (0.0411 US dollar/yr·m^2) were similar estimation with the other LID facilities situated in Seoul Metropolitan such as blue roof and green-blue roof.

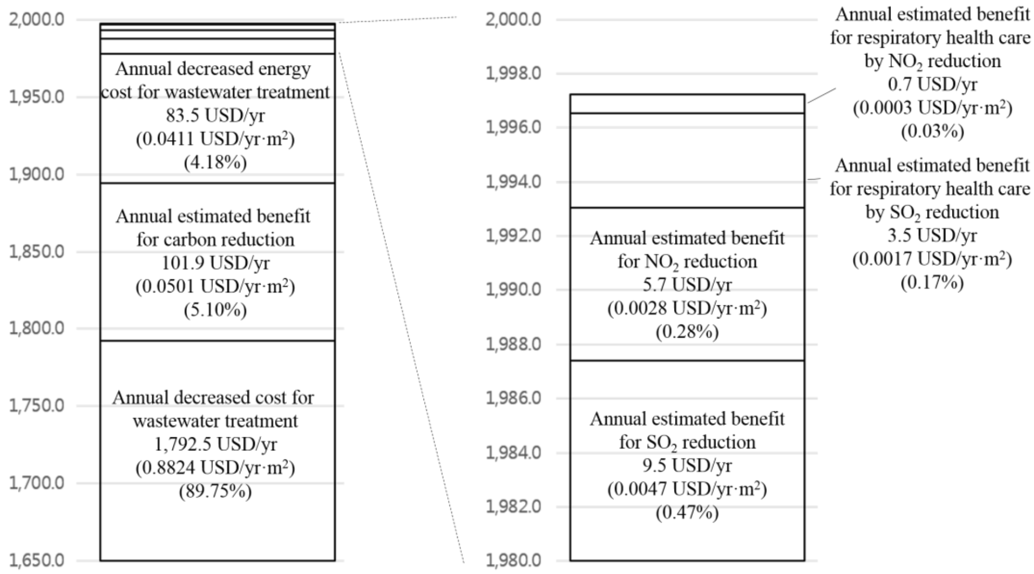


Figure 4. Annual Benefit Assessment for Infiltration Storage Tank

Categorized beneficial characteristics and TBL characteristics for infiltration storage tank are displayed as Figure 5. And those were analyzed according to two-step framework analysis previously explained (Figure 3). In the case of infiltration storage tank, the annual benefit was estimated as about 2,000 US dollars, and it has a value as 1 US dollar/m^2. As previously explained, the infiltration storage tank is underground structure without vegetated area, therefore, the part of economic benefit has the greatest portion. Benefit for air quality improvement was estimated based on indirect benefits of the infiltration storage tank, therefore, it has a portion as less than 1%. And, as shown in Figure 5, decreased electricity cost by wastewater treatment reduction, value for climate change adaptation and benefit of respiratory health care contributed to increase the social benefit.

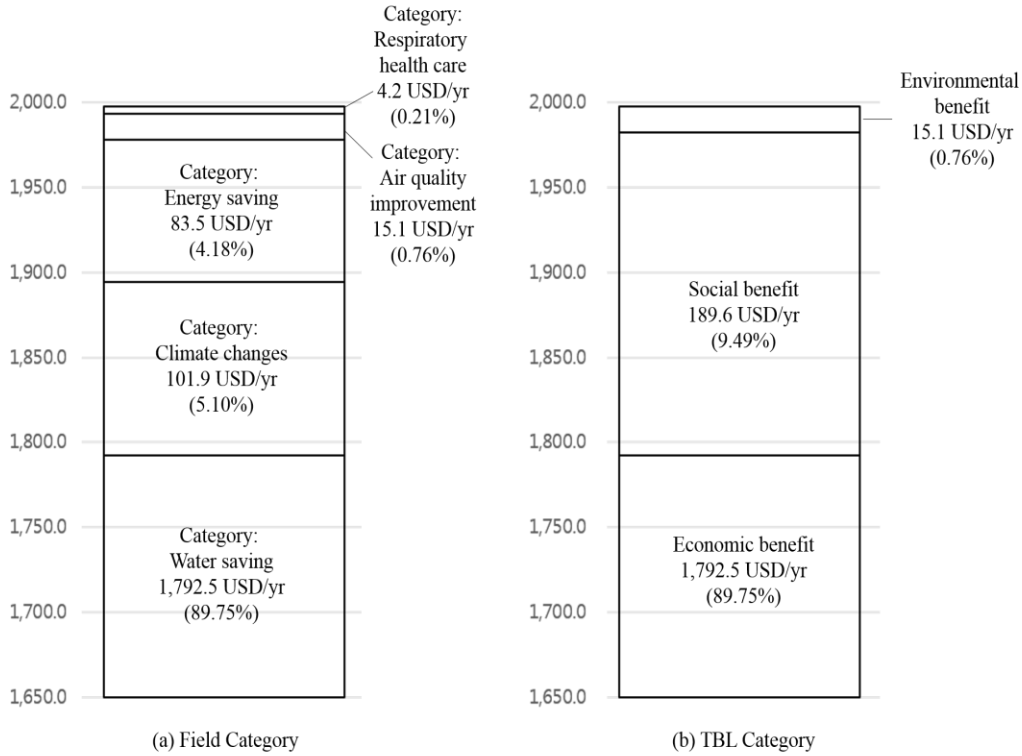


Figure 5. Categorized Annual Benefit Assessment for Infiltration Storage Tank

3.3. Characteristics of Benefit Variation of Permeable Pavement

Figure 6 displays annual beneficial effects for permeable pavement. In the case of infiltration storage tank, annual decreased cost for wastewater treatment has the greatest portion as 87.63% and the other benefits have remained portion as 7.34% for value for carbon reduction, 4.08% for decreased electricity cost for wastewater treatment and less than 1% for indirect benefit for air quality improvement and respiratory health care. Variation characteristic of permeable pavement by benefit analysis contents is seemed as similar with the characteristic of infiltration storage tank. Because, permeable pavement and infiltration storage tank do not have direct effects with respect to energy saving, air quality improvement and climate change adaptation and the only indirect effects were estimated.

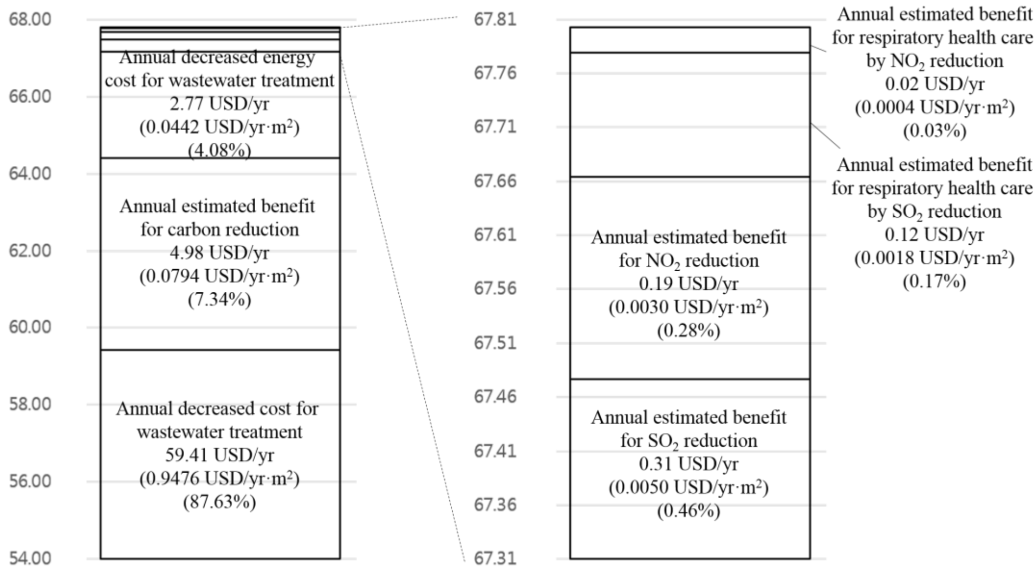


Figure 6. Annual Benefit Assessment for Permeable Pavement

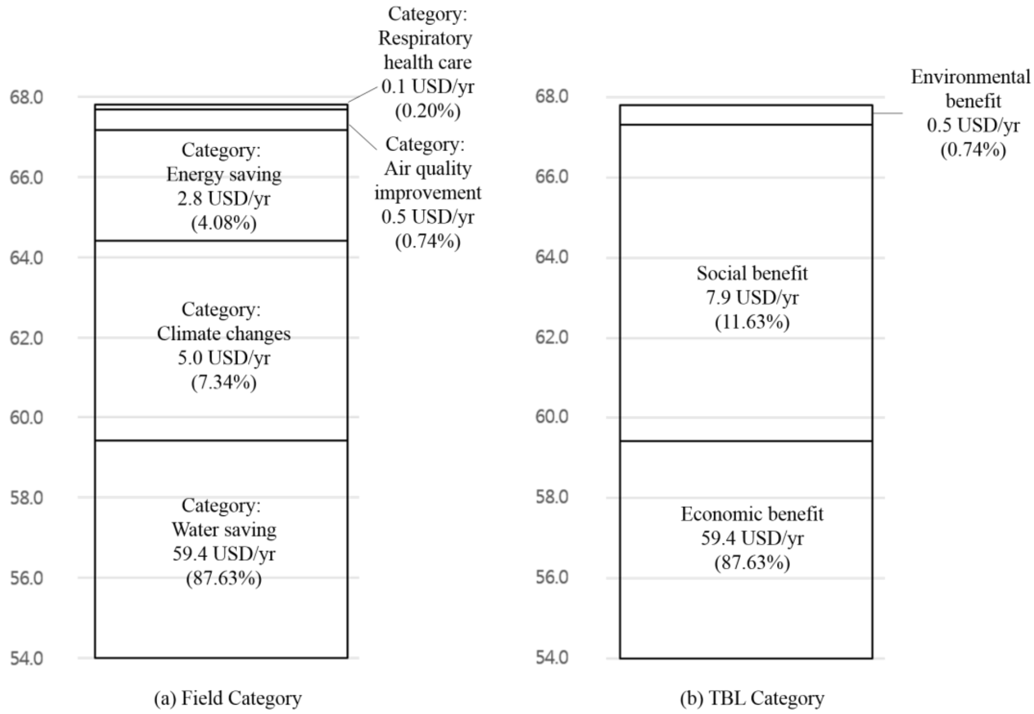


Figure 7. Categorized annual Benefit Assessment for Permeable Pavement

Figure 7 displays categorized beneficial characteristics and TBL characteristics for permeable pavement. In the case of permeable pavement, the annual benefit was estimated as about 68 US dollars, and it has a value as 1 US dollar/m^2 such as infiltration storage tank. Categorized beneficial characteristics and TBL characteristics for permeable pavement also showed similar results with infiltration storage tank. And it is due to that there are not direct effect for energy saving by permeable pavement and direct effects for carbon and air pollutants reduction by vegetation.

4. Conclusion

As results of benefit assessment for infiltration storage tank and permeable pavement demonstrated in Seoul metropolitan, this study concluded as followings,

1) Annual beneficial effects for unit area were estimated as 0.99 dollar/yr·m^2 for infiltration storage tank and 1.10 dollar/yr·m^2 for infiltration storage tank. And application of LID facilities should be determined considering characteristics of each LID facility and environmental conditions of construction area

2) In the case of infiltration storage tank, Triple Bottom Line analysis estimated 1,792.5 US dollar/yr for economic benefit, 189.6 US dollar/yr for social benefit and 15.1 US dollar/yr for environmental benefit. And in the case of permeable pavement, TBL analysis estimated 59.4 US dollar/yr for economic benefit, 7.9 US dollar/yr for social benefit and 0.5 US dollar/yr for environmental benefit. The environmental and social benefits were less than significantly economic benefit and it is due to that underground structure and pavement structure do not have direct effects for energy saving, carbon reduction and air quality improvement.

3) Based on the suggested benefit assessment structure in this study, benefit analysis should be applied to various integrated LID facilities system. And it is needed to consider and estimated the other benefit analysis contents such as decreasing urban heat-island and urban flood by heavy rainfall with complex-scaled research area. And the suggested methodology of benefit analysis to LID facilities also contribute to establish effective cooperation system containing design, construction, and operation.

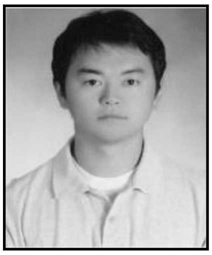
Acknowledgments

This work is supported by the Korea Agency for Infrastructure Technology Advancement (KAIA) grant funded by the Ministry of Land, Infrastructure and Transport (Grant 1615007273).

References

[1] J. H. Suh and I. K. Lee, "The Water Circulation Improvement of Apartment Complex by applying LID Technologies: Focused on the Application of Infiltration Facilities", Journal of the Korean Institute of Landscape Architecture, vol. 41, no. 5, **(2013)**, pp. 68-77.
[2] Center for Neighborhood Technology, "The value of green infrastructure", Chicago, **(2010)**.
[3] United Sates Environmental Protection Agency, "Reducing Stormwater Costs through Low Impact Development Strategies and Practices", Washington, DC, **(2007)**.
[4] S. Wise, J. Braden, D. Ghalayini, J. Grant, C. Kloss, E. MacMullan, S. Morse, F. Montalto, D. Nees, D. Nowak, S. Peck, S. Shaikh and C. Yu, "Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits", Center for Neighborhood Technology, Chicago, **(2010)**.
[5] Center for Neighborhood Technology, "Benefits Details: Green Values Calculator", http://greenvalues.cnt.org/national/benefits_detail.php#reduced-treatment.
[6] S.W. Lee and R. Kim, "Study of Benefit Characteristics for Low Impact Development (LID) Facilities demonstrated in Seoul Metropolitan", Journal of Korean Society of Environmental Engineers, vol. 38, no. 6, **(2016),** pp. 299-308.
[7] E. G. McPherson, J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas, S. E. Maco and Q. Xiao, "Midwest Community Tree Guide: Benefits, Costs, and Strategic Planting", United States Department of Agriculture, Davis, **(2006)**.
[8] Korea Electric Power Cooperation Home Page, http://home.kepco.co.kr/kepco/main.do.
[9] C. D. Scott and R. E. Smalley, "Diagnostic Ultrasound: Principles and Instruments", Journal of Nanosci. Nanotechnology., vol. 3, no. 2, **(2003)**, pp. 75-80.

Authors



Seung Won Lee
seungwonlee@kict.re.kr
Korea Institute of Civil Engineering and Building Technology
Post-Doctoral Researcher

Reeho Kim*
rhkim@kict.re.kr
Korea Institute of Civil Engineering and Building Technology,
Senior Research Fellow:
*Corresponding author