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Review Article

A Review of Recent Developments in Modeling Low-Impact Development Technique

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Abstract

Urban areas are more susceptible to flooding and water body contamination due to the detrimental effects of urbanization. As a result, a sustainable urban drainage system, also known as low impact development (LID) technique, is required. Although this technique can be extensively applied, the planning and design processes are multi-dimensional, multi-variable, and site-specific, which must consider various local conditions and factors. Consequently, these processes can be very complicated and time-consuming for professionals, necessitating support from computer modeling. This study intends to thoroughly explore the idea of LID modeling, various available computer models, and other tools for its optimization and decision-making processes. The most recent trustworthy journal publications that addressed the subjects under discussion were reviewed. This paper used the descriptive and comparative approaches as the analytical methods. According to the findings of the review, Storm Water Management Model (SWMM) is the computer model in LID modeling that is most frequently employed. This model is a fundamental package for dynamic urban rainfall-runoff modeling, and it has the benefits of being lightweight, simple to use, and an intuitive user interface. Besides, this model is public domain (free to use), open source, and interoperable with many hydro modeling applications. A specific LID editor module is also included in this model for modeling different LID units. To acquire the best LID planning and design from multiple criteria and alternatives, it is also necessary to use metaheuristic algorithms as an optimization model and a multi-criteria decision-making (MCDM) model in addition to the rainfall-runoff model. The authors believe combining the hydrologic and hydraulics models integrated with geographical information systems (GIS), metaheuristic algorithms, and MCDM is the most comprehensive and appropriate method for LID modeling in urban watersheds.

Keywords: *LID modeling, MCDA, MCDM, metaheuristic algorithms, SWMM.*

1. INTRODUCTION

Development in urban areas due to urbanization can cause significant changes in the hydrological system and water balance [1]. These changes increase the peak and volume of runoff and shorten the peak time [2]. Therefore, floods potentially occur more frequently, especially if the increase in runoff is not balanced with the development of adequate drainage infrastructures [3]. On the other hand, water infiltration into the soil is decreasing due to the limited areas of green space. It causes groundwater recharge to decrease, which can trigger a lowering in the groundwater table and drought in water bodies [4]. Besides that, an increase in runoff discharge will also trigger a high concentration of pollutants in the water bodies [5], [6]. Thus, changes in urban areas can lead to floods, droughts, and pollution of water bodies if not balanced with sustainable development programs [7], [8].

The concept of Low Impact Development (LID), or Best Management Practices (BMP), becomes a nature-based solution for implementing sustainable development in urban areas [9]. The LID concept is a new paradigm for water management in developing countries that emphasizes conservation and the use of natural features to protect water quality and maintain the hydrological balance of a catchment area so that conditions are like those before development [10], [11], [12]. This LID practice has been adopted in several other countries and is known by different terminology [13]. Low Impact Development (LID) is known and used in Canada and the United States

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[14]. In addition, the term Water Sensitive Urban Design (WSUD) is also known, which is used in Australia, while the Sustainable Urban Drainage System (SUDS) is used in England [13]. In several studies elsewhere, LID practice is also known as Green Infrastructure (GI) or Blue-Green Infrastructure (BGI) [3]. Recently, China also adopted a similar concept for urban flood control known as Sponge City [15], [16]. Singapore uses the term Active, Beautiful, Clean (ABC) Waters, which refers to similar practices to LID [17], [18]. In principle, this practice tries to mimic the natural conditions of a built-up area through various green infrastructures to maintain the drainage function works as it should [15]. However, in implementing LIDs, the planning and design processes cannot be applied in general to all regions but should be specific and consider various local factors and conditions that influence them [19], [20].

In a complex system, LID planning and management can be very challenging for both planners and decision-makers [11], [21]. Even in a small catchment area, the modeling and simulation processes can be complicated and time-consuming if considering many criteria and alternatives [22]. In addition, the LID problems are multi-dimensional and can be dynamic as a function of time and space [23]. Therefore, computer modeling and other supporting tools are needed to bridge these problems. Using computer models and optimization methods can assist urban planners in obtaining an appropriate and optimal design [10]. However, not all available software packages have the same capability in modeling LIDs. This is due to the limitations of the features and their intended use. Therefore, a planner must choose carefully according to his needs and planning goals. Unfortunately, references that discuss LID modeling are still minimal. This paper is intended to comprehensively review the recent developments in LID modeling to obtain an overview of the LID concept and its modeling, available software packages, and supporting tools for its planning and design. Possible future studies required to fill the research gaps are also discussed in this paper.

2. LITERATURE REVIEW

Overview of LID Technique

LID components are divided into two groups based on their function as infiltration and storage. Infiltration-based LID components include vegetative swales, infiltration trenches, recharge ponds, bio-retention cells or rain gardens, sand filter surfaces, and permeable pavements. The storage-based LID components are wetlands, retention ponds, green roofs, and rainwater harvesting systems [24].

Implementing the LID technique can minimize the negative impact of urbanization on runoff [25]. Urbanization triggers an increase in the impervious land surface, reducing the infiltration and groundwater flow and increasing surface runoff. An increase in the impervious surface also has implications for an increase in annual flow [8]. LID facilities can effectively restore the natural function of a catchment area by increasing infiltration and reducing peak runoff discharge and runoff volume [5]. In addition, the runoff peak time can also be delayed compared to the one produced by conventional drainage systems or without LID facilities [26]. LID practices are not only able to improve water balance but also water quality in water bodies [6], [27]. LID techniques can reduce non-point source pollution and improve the conservation rate of natural environment areas [5], [28]. An appropriate LID implementation scenario can effectively reduce the annual pollutant load [27]. LID practices cannot only mitigate the impact of flooding by reducing surface runoff but are also effective in reducing soil erosion [29]. The vegetation surface on the bio-retention cell unit, rain garden, and infiltration trench strengthens the surface structure of the soil and dampens the energy of rain impacts, thereby reducing the potential for land erosion. In addition, the function of vegetation in LID facilities helps increase evapotranspiration, thereby mitigating the effects of urban heat islands (UHI) and improving the microclimate [30]. **Figure 1** illustrates how the LID concept is implemented in a catchment area and its performance in controlling surface runoff. Changes in land use from natural conditions (pre-development) to built-up conditions (post-development) cause rapid rates and high runoff volumes. In contrast, infiltration and evapotranspiration rates are limited (**Figure 1a**). As a result, the peak runoff discharge will be higher while the peak time will be shorter (**Figure 1c**). Implementing the LID practice with various green infrastructures allows rainwater to be retained and stored in depressions, vegetation surfaces, soil layers, or other porous media to attenuate the runoff rate (**Figure 1b**). As a result, the peak runoff discharge can be reduced to near pre-development conditions (**Figure 1c**).

Cities are the most vulnerable areas to the negative impacts of climate change. Extreme rainfall with high intensity tends to increase yearly due to climate change and makes flood prediction more difficult [31], [32]. Implementing LID can mitigate the risks and impacts of urban flooding due to the influence of climate change conditions [9], [33].

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Figure 2 illustrates how climate change affects water balance besides the effects of urbanization. Climate change can increase rainfall and its return period, resulting in excess flow and increased runoff and pollutant rates. Not only in urban areas but also in coastal areas, LID implementation is needed to reduce the risk of flooding due to typhoon storms [34]. LID practices can effectively reduce urban inundation, including hydraulic parameters such as inundation depth, inundation area, and inundation time [35]. However, the hydraulic performance of the LID infrastructures will decrease because of climate change, while the water quality performance will fluctuate with various climate patterns [36]. The uncertainty of the water quality performance of the LID compared to its hydraulic performance is more significant under the influence of climate change [6]. The ability of this LID will decrease in cases of rainfall with high intensity and a higher return period as the soil layer is more quickly saturated [26], [32]. The rainfall intensity and pattern are the major factors influencing the interception and infiltration of rainwater [37]. The rainfall characteristics such as depth and antecedent dry period affect runoff volume and changes in groundwater recharge sensitivity, while rainfall depth and length of the water balance period affect evapotranspiration sensitivity. The long-term storm event should be used in the simulation to fully assess the LID performance [38]. The effectiveness of LID implementation depends on the type and characteristics of the rainfall and the groundwater table [39]. Therefore, its interaction with groundwater flow should also be considered in urban design [40].

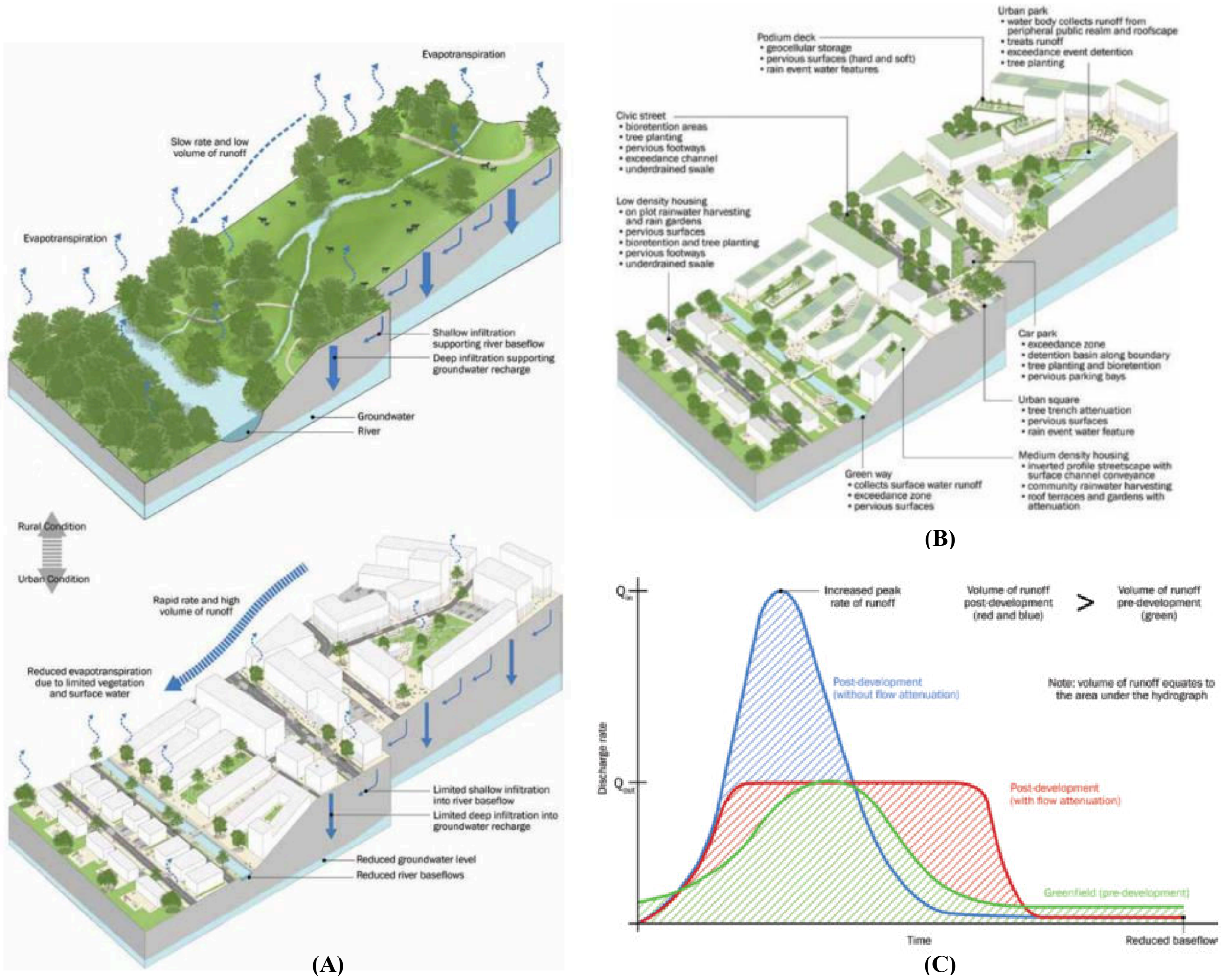

Figure 1. Impacts of urbanization on a catchment (a), examples of commonly used LID for different development types (b), and examples of runoff hydrograph (c) [41]

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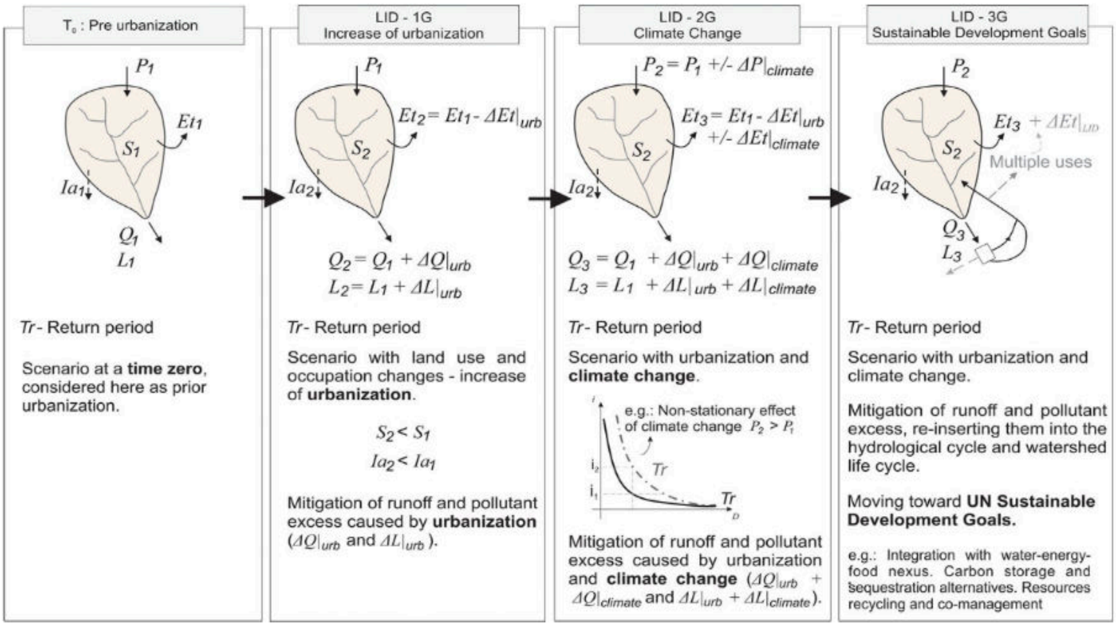

Figure. 2. The concept and evolution of LID practices generations regarding water balance variables and mitigation purposes. In the figure, P_1, Et_1, Q_1, L_1, S_1, Ia_1 and Tr represent, respectively, rainfall, evapotranspiration, runoff, pollutant load, soil storage capacity, infiltration, and return period to base scenario of preurbanization [9]

The capability of LID techniques in reducing the negative impacts of land use change and climate change supports the importance of applying non-structural methods compared to structural methods in planning urban areas, especially if ecological and environmental factors are the main considerations [5]. LID practices should be implemented concurrently with improving drainage facilities for successful runoff management [8], [42]. Spatial distribution and placement of LIDs need to be planned effectively to obtain the maximum effect of reducing runoff volume [25]. Implementation of a combination of various LID facilities produces the best performance compared to their individual implementations [8], [28]. However, it must be realized that implementing these LID facilities has consequences, which will increase the costs of the construction of drainage infrastructure [11], [27]. Nevertheless, the practice of LID is highly recommended because it can increase the use of rainwater while reducing the problem of local urban flooding [26]. Local adaptation strategies using LID practices are more effective than climate change mitigation [33]. Therefore, an optimal LID planning and design strategy is necessary to achieve maximum performance but with realistic construction costs.

Computer Models (Software Packages)

Field experiments can be used to analyze the performance of LID components in managing the quantity and quality of surface runoff, but doing so requires a lot of resources and materials. In particular, experiments on a large scale are severely constrained by available resources and the costs of conducting them [43]. Using computer models can bridge the need for this analysis [24]. An accurate and credible model is required for optimal LID evaluation and planning [44]. In various case studies that have been carried out, several computer models have often been used, including SWMM, SUSTAIN, InfoWorks, and MOUSE [43]. InfoWorks ICM can be used to simulate the urban rainfall-runoff pollution model since the model has hydrologic and water quality modules [45]. Besides that, there is also a Rainwater+ model to estimate runoff volume and LID planning [46]. LID modeling can be utilized in the preliminary study, planning, and detail design phases [47].

Kaykhosravi et al. [48] reviewed eleven selected LID models based on aspects of model features and capabilities, hydrological modeling, and hydraulics modeling. The review results explained that three of the eleven models (GIF-Mod, HYDRUS 1D, and RECARGA) are suitable for LID planning during the research phase. The other three models (GREEN VALUE, L-THIA-LID, and WBM) are only appropriate for the conceptual design of LID. Four other models (HEC-HMS, MIKE Urban, PCSWMM, and SWAT) are recommended for preliminary purposes and detailed LID design. The Win-SLAM model is only recommended at the detailed design phase. The review results also confirm that most LID models need improved capabilities to model the infiltration process. Developing a model that can optimize LID spatial planning is also necessary.

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Among the many software packages available, SWMM is currently the most widely used tool in Sponge City and LID modeling [22], [49]. SWMM is a powerful dynamic rainfall-runoff simulation model capable of simulating a range of areas from a single, uniform subcatchment to an entire city drainage system [47]. Using the SWMM to model natural events of the rainfall-runoff process can give planners a comprehensive view of the drainage system and floodplains within the city [42]. Other models that are also widely used include SUSTAIN, Hydrus-1D, PCSWMM, and MIKE Urban [49]. SUSTAIN is a decision support system that assists stormwater management professionals with developing and implementing plans for flow and pollution control measures to protect source waters and meet water quality goals. SUSTAIN allows watershed and stormwater practitioners to develop, evaluate, and select optimal best management practice (BMP) combinations at various watershed scales based on cost and effectiveness [50]. Liu et al. [49] also explained that of the available software packages, only SWMM, SUSTAIN, and MIKE Urban provide special modules for modeling LID units. MIKE Urban (particularly known as MIKE+) model uses the SWMM engine; therefore, it has all the functionalities of SWMM. However, the advantage of MIKE Urban over SWMM is the capability to simulate 2D overland flow and GIS integration, unlike in SWMM [51]. Like MIKE Urban, the PCSWMM model also uses the SWMM engine, which is integrated with GIS and capable of modeling 2D flood inundations [52]. Therefore, both MIKE URBAN and PCSWMM models are primarily used to overcome the limitation of one-dimensional (1D) SWMM in simulating flood extent and flood inundation [51]. The SWMM, MIKE Urban, and PCSWMM models continue to be developed today, but the SUSTAIN model stopped development in 2014. Even so, the SUSTAIN model is still often used today because of its ability to optimize the implementation of LID facilities in urban drainage systems using a genetic algorithm (NSGA-II) that is not yet available in other similar models. **Figure 3** provides information on the most widely used software packages for Sponge City modeling, while **Table 1** details and compares the five software packages most used for LID modeling.

One of the positive benefits of implementing LID is providing recharge for groundwater flows. In addition, LID performance is also affected by groundwater flow. Therefore, its interaction with groundwater flow must be taken into account to obtain a better model representation [40]. Unfortunately, no LID model can simulate the effect on the groundwater recharge contribution for all the software packages mentioned in the previous section. Mooers et al. [4] integrated surface runoff and groundwater flow models using a combination of the PCSWMM and MODFLOW models. The PCSWMM model calculates the infiltration flow rate from the LID implementation. It is then used as input in a groundwater recharge simulation using the MODFLOW model to see its effect on potential groundwater availability. The research results show that implementing LID can help restore groundwater conditions to their natural state. Considering the interaction between LID and groundwater flow, which influence each other, it is necessary to improve or develop LID modules in SWMM that can interact directly with this groundwater flow [40]. In addition to its interaction with groundwater flow, LID performance is also affected by climate change [6]. However, no model available has the facilities to consider the effects of climate change on LID practices [49].

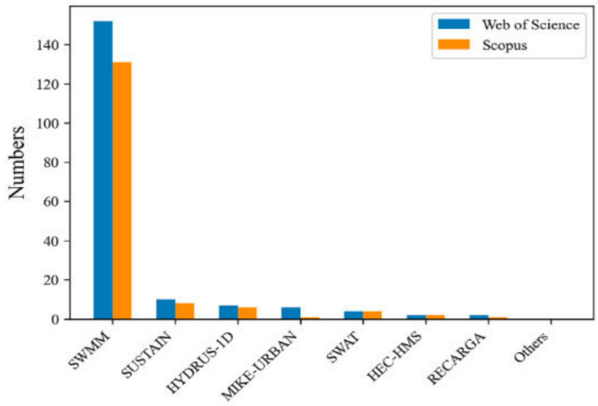

Figure 3. The most widely used software packages in LID or Sponge City modeling research between January 1st, 2000 and July 3rd, 2021 [49]

Table 1. Most used software packages for LID Modeling

Model Name	Developer	Latest Release	Main Function	GIS Integrated	2D Flow Capability	Licensed	Advantages	Disadvantages
SWMM	US EPA	Version 5.2.3 (2023)	Dynamic rainfall-runoff modeling and 1D flow of urban drainage system	No	No	No	- Basic package for urban rainfall-runoff modeling. - Simple, light, and user-friendly interface. - Public domain and open source.	- Not support GIS (limited). - Cannot model 2D overland flow. - Standalone urban collection system module

Model Name	Developer	Latest Release	Main Function	GIS Integrated	2D Flow Capability	Licensed	Advantages	Disadvantages
							- Compatible with other software packages.	
SUSTAIN	US EPA	Version 1.2 (2014)	Hydrologic and water quality modeling in watersheds and urban streams. Optimize best management practice (BMP) combinations at multiple-scale watersheds based on cost and effectiveness.	Yes	No	No	- Support GIS - Has a BMP optimization module that can be used to identify cost-effective BMP placement and selection strategies. - Public domain	- Cannot model 2D overland flow. - Specifically developed for the LID planning model
MIKE Urban (MIKE+)	DHI	MIKE+ (2023)	Integrated modeling of complete water systems: water distribution networks, water collection systems, river networks, and flooding	Yes	Yes	Yes	- Supported and integrated with GIS (ArcGIS Pro). - Integrated water systems modeling. - Can perform 2D flow simulation. - Can run multiple scenarios or projects	- Requires high specification of a personal computer. - For commercial and professional users (while providing academic/ educational licenses).
PCSWMM	CHI	Version 7.5 (2022)	Advanced modeling software for stormwater, wastewater, watershed, and water distribution systems	Yes	Yes	Yes	- Supported and integrated with GIS (standalone GIS engine). - Integrated water systems modeling. - Can perform 2D flow simulation. - Can run multiple scenarios or projects.	- Requires high specification of a personal computer. - For commercial and professional users (while providing academic/ educational licenses).
HYDRUS-1D	PC-Progress	Version 4.17 (2019)	Hydrologic, heat, solute transport modeling of saturated-unsaturated water flow in vertically soil layers	No	No	No	- Can model multiple layers of soil medium. - Can model solute transport within soil layers. - Consider the losses caused by root uptake. - Ideal to model the bio-retention and rain garden column performance	- Not specifically to model LID performance (except bio-retention and rain garden). - Cannot model other LID components.

Optimization and Design of LID

LID Optimization Using Metaheuristic Algorithms

The LID optimization model is needed for an effective LID infrastructure design to provide maximum performance in reducing runoff and controlling floods. Because flood management and control optimization are often large-scale, nonlinear, and complex problems, the traditional optimization methods for solving them are time-consuming and computationally expensive, making them practically inapplicable [53]. Recently, metaheuristic algorithms have been widely used to solve spatial LID optimization problems [54]. The metaheuristic algorithm is an optimization method that seeks optimal (near-optimal) solutions to optimization problems. This algorithm is a derivative-free technique and has simplicity, flexibility, and the ability to avoid local optima [55]. The behavior of the metaheuristic algorithm is stochastic, in which this method will start the optimization process by making a random solution [56]. Among the many developed metaheuristic methods, genetic algorithm (GA), particle swarm optimization (PSO), ant colony optimization (ACO), and simulated annealing (SA) are the most frequently used to find solutions to optimization problems in the LID planning process [21], [36], [54], [55].

Lu & Qin [57] developed a simulation-optimization model for LID design by combining fuzzy simulation and optimization models (SWMM-GA). The LID optimization-simulation results are then compared to the traditional deterministic and stochastic models. The research results show that the simulation-optimization model developed provides flexibility in defining and accessing uncertainties from LID hydrological modeling. Nevertheless, the developed simulation-optimization model has limitations regarding large computational needs. Bahrami et al. [58] combined the SWMM model and GA to simulate and optimize the performance and cost of LID construction. The research results indicate that it is important to investigate the sensitivity of the units designed in the system and study area, which are trade-offs between different possible decisions and uncertainties in future developments in a watershed area. J. J. Huang et al. [59] also carried out LID planning optimization

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simulations using a combination of the SWMM-GA model. Optimization objective functions include runoff reduction, LID area, and life cycle cost. The research results show that combining LID infrastructures is the most effective in reducing runoff through a long-term simulation (10-year rainfall event). Bio-retention cells are more recommended when considering the area of LID, while green roofs are more recommended considering life cycle costs. Eckart et al. [60] developed a multi-objective LID optimization model by combining the SWMM model and the Borg Multi-objective Evolutionary Algorithm (Borg MOEA), an advanced genetic algorithm (GA). The objective functions of optimization include the ability to reduce volume and peak of runoff, as well as construction costs. The model was tested for a sewershed with poor infiltration characteristics in Windsor, Ontario, Canada. For this study, they determined that infiltration trenches would be the most cost effective LID (of those studied), particularly for reducing peak flow. Additionally, it is the most cost effective to focus on implementing LIDs in high runoff areas first. For the sewershed in question, LIDs were able to make significant reductions in both storm sewer peak flow (up to 29%) and total runoff (up to 13%) despite the poor infiltration characteristics of the sewershed. The reductions in peak flow were achieved by building detention storage into the catchments with LIDs. Hou et al. [61] developed an LID planning optimization model (scale, type, and location) based on the *p*-Median model and the Ant Colony Optimization (ACO) algorithm. The research results explain that GIS is essential in planning the scale, type, and location of LID placement, potentially useful for constructing LID facilities. Factors to be considered in planning and constructing LIDs include support from regional water resources endowments, planning and control objectives, and land use. In fact, the construction of LID facilities should consider additional factors, such as development intensity, economic development level, and specialized planning. Specialized planning includes municipal water system planning, green space system planning, drainage and waterlogging prevention planning, and road traffic planning. The ACO algorithm can calculate model solutions faster than GA. Other studies reveal that the ACO algorithm is good and stable for optimizing LID problems [62]. C.-L. Huang et al. [63] developed a model for optimizing LID infrastructure planning for the percentage of runoff reduction and Benefit-Cost Ratio using a combination of SWMM and Simulated Annealing (SA) algorithms within megacity areas. The research results show that the LID infrastructures can reduce the peak discharge by about 30% and delay the peak time significantly by up to 20% in the entire watershed, while in the subcatchment area they are around 23.5% and 37.5%, respectively. Prioritized LID infrastructures are green roofs and bio-retention cells. **Table 2** briefly explains several metaheuristic algorithms application studies and their significance in the LID optimization problems.

Leimgruber et al. [64] analyzed the LID infrastructure selection strategy based on water balance criteria (reduction of runoff volume, increase of evapotranspiration, and groundwater recharge), the demand for land (the land availability in urban areas, where available land is rare and expensive), and the life-cycle costs. The research results confirm that there is no specific optimal LID strategy for an area where every planner must choose from a combination of methods tailored to a particular goal.

Table 2. Metaheuristic algorithms application in the LID optimization problems

Algorithm / Description	Objective	Criteria / Indicators	Result Significances	Limitations	References
Ant Colony Optimization (ACO) A global search algorithm based on multiagent simulation evolution with distributed control, self-organization, positive feedback, and potential parallelism. It is inspired by the ants' behavior to locate the food location.	Spatially Optimize locations of LID facilities: rain barrels, porous pavement, rain gardens, vegetated swales, detention ponds, bio-retention ponds, and vegetation buffers.	Available harvested rainwater (affected by precipitation, plant interception, depression filling, surface infiltration, and evapotranspiration), construction cost, land use	The proposed method can effectively guide LID construction for practitioners and stakeholders to determine the scales, types, and locations of LID practices. The ACO algorithm can generate the optimal solution for the p-median model with a small CPU time (faster than the GA algorithm)	The study did not consider additional factors, such as development intensity, economic development, and specialized planning. Peak runoff control and rainwater resource utilization were not included as control objectives.	[61]
Simulated Annealing (SA) A general probability optimization algorithm. Its principle is similar to that of metal annealing by	Optimizing the amounts, types, sizes, and layouts of the LID devices, including permeable pavement, bio-retention cell,	Benefit/cost ratio (BCR) as a function of annual benefits and costs	The technical approach by linking the SA algorithm and SWMM enables an automatic and effective optimization process	The social benefit and cost were not included in the objective function calculation. The algorithm was not compared to other	[63]

Algorithm / Description	Objective	Criteria / Indicators	Result Significances	Limitations	References
applying thermodynamic theories in statistics.	infiltration cell, rain barrel, vegetative swales, green roof, and newly developed tree box.			metaheuristic algorithms	
Multi-Objective Particle Swarm Optimization (MOPSO) An algorithm is based on searching the solution space based on the movement of a group of particles towards the best position they have been previously facing, hoping that they will achieve a better position during the process. This method is inspired by bird and fish flock movement behavior.	Optimizing the design of type and area of LID-BMP practices (infiltration trenches, bio-retention basins, and permeable pavements) for urban runoff water quality control	Peak TSS concentration	The proposed hybrid SWMM-MOPSO simulation-optimization model was instrumental in the optimal designing of the LID-BMPs and controlling runoff water quality.	The cost variable was not considered in the optimization process. The algorithm was not compared to other metaheuristic algorithms.	[54]
Harmony Search (HS) An evolutionary optimization method inspired by the process that a composer follows to harmonize a piece of music	Optimizing the place and size of online/ offline detention ponds in urban drainage systems	Flood volume reduction	The proposed coupled SWMM-HS can result in a better option for designing the size and location between online or offline ponds.	The optimization processes were time-consuming. It took 21 days to find the optimal design for each case.	[53]
Genetic Algorithm (GA) An optimization algorithm inspired by natural selection and genetic mechanism theory. The genetic operation of GA mainly includes three main procedures: selection, crossover, and mutation.	Optimizing the selection and layout of LID practices	Runoff reduction, area of LID, and life cycle cost	The study proved that GA is feasible for LID planning in urban areas. The proposed method can help decision-makers determine the LID plan more scientifically based on the SWMM model and GA.	The water quality benefit was not included as an objective or optimization target. Besides, the effect of climate change was ignored in this study.	[59]

LID Design Using Decision-Making Method

Multi-criteria decision analysis (MCDA) is a tool developed in decision theory to solve operational research problems. In this method, a decision maker weighs a set of evaluation criteria to choose the best alternative [65]. The MCDA method has been implemented to assist in modeling and simulating systems that require decision-making by individuals or groups [66]. The advantages of the MCDA are that the method is easy to use and the criteria are not considered proportionate. The MCDA approach in flood risk studies and management is considered superior to statistical methods.

The multi-criteria decision-making method, also known as multi-criteria decision-making (MCDM) or MCDA, is an essential tool needed to determine the priority of suitable LID infrastructure alternatives based on various criteria in a study area. Among the many MCDM methods, two methods, namely the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), are the most well-known methods and have been widely used in various fields and real-world problems [67], [68]. Although these two methods have been widely applied, their implementation in the LID concept is still minimal and relatively new. Several studies have been conducted by Gogate et al. [69], Liang et al. [70], and Koc et al. [71]. In their research, the researchers explained the framework of how the two AHP and TOPSIS methods succeeded in prioritizing the selection of the best LID strategy for decision-makers. Mousavi et al. [65] stated that MCDM, especially TOPSIS, has an advantage in applying discrete alternative challenges to directly identify the best alternatives in solving real-world problems. Also, this method is relatively quickly implemented and can be further used for other watercourse management in urbanized areas, especially in developing countries. It performs a primary analysis to define the suitable techniques that could be applied to watercourse interventions [67]. Another study conducted by Z. Zhang et al. [72] used a combination of the AHP and TOPSIS methods to evaluate urban flood resilience. The AHP method is used to weigh each criterion and indicator that influences the selection of alternatives and synthesizes expert judgment, while the TOPSIS method is used to rank the best alternative in social and economic

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recoverability. Other MCDM methods used in different LID studies include the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) [73], Criteria Importance Through Intercriteria Correlation (CRITIC) [74]. Nonetheless, the proposed framework is not necessarily suitable when applied to different study areas, so it needs to be tested extensively [75]. This is because the survey and weighting methods greatly determine the analysis and can produce widely varying results [66]. In addition, the different selection criteria, such as technical, environmental, social, and economic factors, can also affect the results. Campos et al. [67] recommend using sustainability criteria, including environmental, social, and economic aspects, for a comprehensive analysis in selecting urban watercourse management strategies. **Figure 4** illustrates several criteria, including each factor that needs to be considered in the engineering design of LID selection, while **Table 3** lists the LID measure selection criteria and MCDM method used based on several studies conducted.

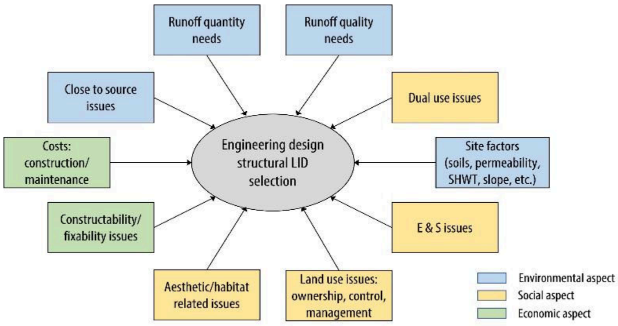

Figure. 4. Structural LID measure selection considerations (adapted from Cahill, 2012)

Table 3. LID measure selection criteria and MCDM method used based on several studies conducted

LID unit	Selection Criteria	MCDM Method	Result Significances	References
Green roof, bio-retention, grass swale, detention basin, porous pavement	Effectiveness: peak flow, runoff volume, and TSS reduction Cost: landuse, construction, O&M	TOPSIS	The cost weight significantly impacts multi-criteria decision-making, and all strategies may be classified into three categories: effectiveness, cost, and stability.	[76]
Green roof, permeable pavement, bio-retention cell, vegetated swale	Runoff volume control, peak flow reduction, pollutant removal, life cycle cost	TOPSIS	Decision-makers can consider different cost weights to determine the optimal scenario of LID implementation.	[77]
Bio-retention cell, permeable pavement	Water quantity: VCRa (volume capture ratio of annual rainfall), river storage depth Water quality: annual pollutant reduction, pollutant concentration	TOPSIS	The integrated assessment framework can provide insights into ways to take into account the comprehensive benefits of LID constructions and can also be applied to the optimal selection and performance effect assessment of LID facilities in other Sponge City projects.	[78]
Bio-retention cell, permeable pavement, rain barrel	Resilience, flood volume, flood duration time, hydraulic performance index, annual runoff volume control, rainfall usage, pollution control, social acceptability, greenhouse gas emissions, and cost	AHP & TOPSIS	The larger LID construction area did not significantly improve the efficiency but cost more money. The integrated framework demonstrated enables the selection of a design scheme with optimal resiliency and sustainability for decision-makers.	[70]
Green roof, bio-retention cell, permeable pavement, infiltration trench	Environmental: quantity (peak runoff and runoff volume reduction), quality (TSS, COD, TN, TP reduction), impact on flora/fauna, CO2 emission Economic: Initial investment cost, operation cost, operation feasibility, LID return period Social: aesthetic, community resistance, employment probability	AHP - TOPSIS	community resistance, operation feasibility, and quantitative benefits were the most significant criteria for LID scenario selection in social, economic, and environmental aspects, respectively	[71]
Rain garden, green roof, permeable pavement	Runoff control rate, SS load reduction, construction costs	TOPSIS	the weighting method using TOPSIS can achieve the best cost performance (minimize construction costs) while reducing the runoff and SS load	[79]
Bio-retention, grassed swale, sunken green space, permeable pavement, storage tank	Environmental benefits: water quantity (peak reduction, runoff reduction, peak delay), water quality (COD, TSS, TN, TP) Economic benefits: construction cost, maintenance cost, operation performance (design, engineering, and operation feasibility) Social benefits: water reuse function, landscape function, ecological service function	AHP	The proposed evaluation system can provide insights into ways to consider the comprehensive benefits of LID practices and optimize design schemes before sponge city construction.	[75]

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3. DISCUSSION

The negative impacts of urbanization and development in urban areas are causing increased surface runoff and degradation of groundwater flow. These changes have implications in increasing the intensity and frequency of floods. The LID technique is necessary to restore the hydrological balance in urban areas to their natural conditions. This technique can reduce the volume and discharge of floods, increase the recharge capacity of groundwater flows, reduce pollution of water bodies, and maintain the microclimate simultaneously. Therefore, this technique should be implemented in every development within urban areas. Furthermore, this technique should be a future drainage development concept that has become a widely and massively applied trend in any city area.

Although the LID technique can be widely implemented, its design and construction must consider local conditions such as climatological factors, land cover, physical soil properties, and groundwater level [49]. For example, a bio-retention cell and permeable pavement system design applied to areas with naturally permeable soils will differ from those designed for soils with more impermeable soil types. Besides the technical aspect, the planning process should address other factors such as social, environmental, and financial capability.

Several models of the available software packages have included LID modules specifically for complex drainage system planning needs. However, none of the available models has taken into account the influence of groundwater flows and their interactions with each other. The LID module also cannot consider the effect of climate change factors. In addition, because the LID module embedded is based on the SWMM engine, the water quality model is still limited to physical reactions (dilution process). However, chemical and biological reactions have not been taken into account [80], [81]. Therefore, an improvement in the LID module is required to consider the factors of groundwater flow, climate changes that affect water balance, and chemical and biological reactions to calculate the water quality of outflow. The currently available rainfall-runoff models do not yet include a tool for auto-calibration. This tool is necessary, considering that sensitivity analysis and calibration-validation processes are crucial for obtaining a credible model.

LID planning requires an optimization process so that the developed drainage system has maximum performance in reducing runoff and flood potential while minimizing the cost and area for construction. The optimization process with a metaheuristic algorithm approach is the best alternative for solving LID optimization problems because it is easier and faster than traditional optimization methods. However, the weakness of the metaheuristic algorithm method is that the solution obtained is not exactly optimal (near optimal) and has the potential to get trapped in local optima. The suggested metaheuristic algorithm for solving the LID problem is a population-based algorithm that has the benefit of avoiding local optima. Based on this type of algorithm, evolution-based algorithms such as the GA are the most common for use in LID optimization. However, swarm intelligence-based algorithms such as PSO and ACO are starting to be widely used because they are superior in the speed of getting solutions compared to GA. Physics-based algorithms such as SA and HS are still very rarely used, as well as human behavior-based algorithms. It is an opportunity for future studies to obtain a complete and more varied performance result using metaheuristic algorithms in LID optimization problems. Several studies have been conducted to optimize LID using metaheuristic methods, but many research gaps exist in using other available algorithms. Therefore, research that compares several metaheuristic methods to an LID optimization problem is needed to obtain a clearer picture of the advantages and disadvantages of each algorithm.

Designing LID also requires an MCDM approach due to the many LID infrastructures available and the criteria and alternatives that vary widely in its implementation in an urban area. The decision-makers must choose the best option from several alternatives that are suitable for implementation. The selection criteria for the most comprehensive LID design and planning should be based on a sustainability index, including environmental, economic, and social aspects. Of the many available MCDM techniques, the AHP and TOPSIS methods are the most frequently used in LID infrastructure planning. Both methods are easy to use and can directly obtain the best alternative from several specified criteria.

The combination of hydrologic and hydraulics models integrated with GIS, metaheuristic algorithms, and MCDM can accommodate most of the analyses required for optimal LID planning and design. This approach should be considered the most comprehensive method in studying and managing flood reduction spatially within urban watersheds. Future studies can lead to the preparation of a framework from a combination of these models, which are then tested at various scales of urban catchments with specific local conditions. Of the different types of LIDs that can be modeled, studies on modeling infiltration wells are still very few. Besides that, the LID module embedded in the SWMM has not yet included the infiltration well component. Further studies on modeling infiltration well using SWMM need to be carried out to make its implementation wider, especially for urban areas in Indonesia that have been familiar with such LID unit.

4. CONCLUSION

Based on the analysis above, it can be concluded that computer modeling has a crucial role in LID planning and design processes. It is necessary to consider that the developed drainage system can be very complicated, with various technical and non-technical factors considered. A planner can comprehensively analyze the designed system with computer modeling for optimal performance. Various computer models capable of modeling different LID infrastructures are now available. Among these computer models, SWMM is the most frequently used in many LID studies and projects. Nonetheless, the capability of SWMM to model LID still needs to be improved and further developed. This is because the LID editor module embedded in SWMM has not considered the interaction of LID with groundwater flow and the effects of climate change. Besides that, the water quality module in SWMM is also relatively simple, which only considers the physical process of pollutant concentration within the flow but not the chemical and biological reactions. The automatic calibration and validation tools should also be added to SWMM, considering that simulation output from the LID model must be credible.

Combining hydrologic and hydraulics models integrated with GIS, metaheuristic algorithms, and MCDM is the most comprehensive approach in LID planning and design phases. Future studies should lead to the preparation of a framework from a combination of these models, which are then tested at various catchment scales in different characteristic urban areas. Eventhough the most frequently used metaheuristic algorithm is GA, but studies of using other algorithms in LID optimization should be addressed. Several other algorithms, such as ACO, PSO, and SA, are considered superior to GA in obtaining solutions. The MCDM techniques recommended in selecting LID design are AHP and TOPSIS.

With various computer models and digital data support available recently, such as aerial images, high-resolution satellite images, satellite rainfall data, and other easily accessible data, the LID technique should be studied and implemented massively in developing countries, including Indonesia. Another LID unit, namely infiltration well, has been familiar, especially in big cities in Indonesia. However, the modeling process becomes challenging because this LID unit is not yet available in the LID editor module of SWMM. Therefore, further research should also be recommended that focuses on modeling infiltration wells using SWMM.

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