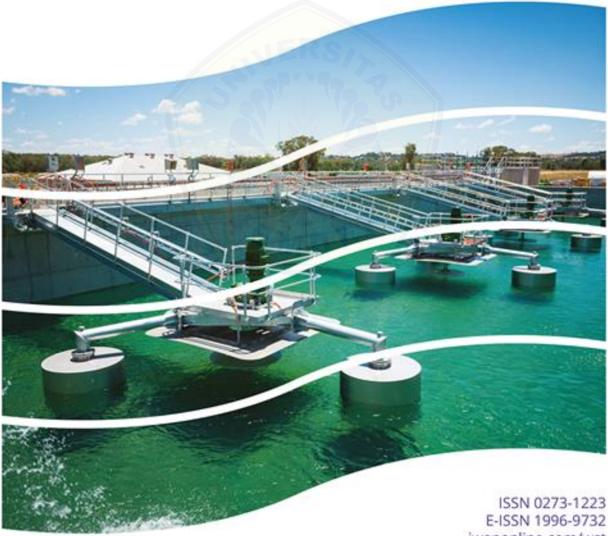
Vol 87 | Issue 6 | March 2023

IWA PUBLISHING

Water Science & Technology



ISSN 0273-1223
E-ISSN 1996-9732
iwaponline.com/wst

WATER SCIENCE AND TECHNOLOGY

ISSN / eISSN **0273-1223 / 1996-9732**
Publisher **IWA PUBLISHING, REPUBLIC-EXPORT BLDG, UNITS 1 04 & 1 05, 1 CLOVE CRESCENT, LONDON, England, E14 2BA**

About

Water Science and Technology publishes peer-reviewed papers on all aspects of the science and technology of water and wastewater. Papers are selected by a rigorous peer review procedure with the aim of rapid and wide dissemination of research results, development and application of new techniques, and related managerial and policy issues. Scientists, engineers, consultants, managers and policy-makers will find this journal essential as a permanent record of progress of research activities and their practical applications.

General Information

Society or Institution	International Water Association	**Journal Website**	Visit Site
Publisher Website	Visit Site	**1st Year Published**	1981
Frequency	Semi-monthly	**Issues Per Year**	24
Country / Region	ENGLAND	**Primary Language**	English
Avg. Number of Weeks from Submission to Publication	11	**Article DOIs**	Yes

Web of Science Coverage

← Show this widget in your own website

Just copy the code below and paste within your html code:

`<a href="https://www.scim`

Explore, visually communicate and make sense of data with our **new data visualization tool**.

Metrics based on Scopus® data as of April 2022

Water Science & Technology

IWA PUBLISHING

Water Science & Technology Vol 00 No 0, 1 doi: 10.2166/wst.2023.095

Enhancing stormwater management with low impact development (LID): a review of the rain barrel, bioretention, and permeable pavement applicability in Indonesia

Fidyasari Kusuma Putri, Entin Hidayah* and Mokhammad Farid Ma'ruf

Department of Civil Engineering, Jember University, Jl. Kalimantan Tegalboto No.37, Jember, Jawa Timur 68121, Indonesia
*Corresponding author. E-mail: entin.teknik@unej.ac.id

EH, 0000-0002-1233-6850

ABSTRACT

Low impact development (LID) is a sustainable land use and planning strategy that aims to minimize the environmental impacts of development. Community can enhance their water resources and create sustainable and resilient neighborhood. This approach has demonstrated success in managing stormwater and promoting water reuse globally, however, its suitability in developing countries like Indonesia remains uncertain and requires further investigation. The implementation of LID in developing countries may face several challenges including high-density and complex drainage networks, combined sewer usage, clay soil type, irregular housing layouts, community socio-economic characteristics, affordability, cost, and the availability of regulations and policies. With proper planning and site-specific strategies, LID can be implemented effectively in Indonesia. Clear regulations secured funding source and community-based LID are all essential for successful LID deployment. This paper can be used as a starting point for considering LID implementation in Indonesia and other countries with similar characteristics.

Key words: bioretention, low impact development, permeable pavement, rain barrel, stormwater management, urban drainage

HIGHLIGHTS

- The applicability of LID in developing countries like Indonesia remains uncertain and requires further investigation.
- The implementation of LID in Indonesia faces several challenges including high-density and complex drainage networks, combined sewer usage, clayey soil type, irregular housing layouts, community socio-economic, affordability, and cost, coupled with the availability of regulations and policies.

ABBREVIATIONS

LID	Low impact development
RB	Rain barrel
BR	Bioretention
PP	Permeable pavement

1. INTRODUCTION

Low impact development (LID) is a protocol with more sustainable land use and planning approach aimed to tackle the negative impacts of development on the environment (Pour *et al.* 2020). The goal of LID is to decrease the amount of runoff volume (Zhu *et al.* 2019b), and pollutants by development (Taghizadeh *et al.* 2021), along with improving the ability of natural landscapes to absorb, store, and purify water (Thiagarajan *et al.* 2018). LID aims to promote sustainable development by balancing economic, social, and environmental goals, and by protecting natural resources as ecosystems that are essential to our health (Nguyen *et al.* 2019). Additionally, using techniques that resemble the natural water cycle, LID tries to manage stormwater runoff at the source and preserve water quality (Rezaei *et al.* 2019). There is various type of LID, which are rain barrels (RB), bioretention (BR), and permeable pavement (PP) are three popular LID practices (Si *et al.* 2022).

There have been many studies and articles published on LID practices and their effectiveness in reducing runoff volume and improving water quality. Some of the findings from these studies include the BR capability on improving groundwater recharge in Canada (Mooers *et al.* 2018) and enhance local biodiversity in the USA (Morash *et al.* 2019), RB ability to reduce flood under different climate scenarios in Malaysia (Liew *et al.* 2021). Furthermore, PP can significantly weaken not only the volume and runoff rate in China (Yin *et al.* 2020). The combination of those three has also been found effectively remove pollutants (Rong *et al.* 2021), such as organic matter like BOD (biological oxygen demand) and COD (chemical oxygen demand) (Mohammed *et al.* 2022), sediment like TSS (total suspended solids) (Rezaei *et al.* 2019), nutrients like TP (total phosphorus) and TN (total nitrogen) (Dong *et al.* 2020), heavy metals like Cu (Copper), Pb (Lead), and Zn (Zinc) (Talebzadeh *et al.* 2021), as long as pathogen like FCRA (*Fecal Coliform*) (Rahman *et al.* 2019). Hence, this after-treatment water is reused, even for drinking water purposes (Gispert *et al.* 2018).

Overall, the ability of LID to achieve sustainable water management is demonstrated by its success in managing stormwater and promoting water reuse on a global scale (Nguyen *et al.* 2019) and enhancing the resilience of communities (Batalini de Macedo *et al.* 2022). By adopting and implementing LID, communities can improve their water resources (Li *et al.* 2019a), protect the environment (Ishaq *et al.* 2019), and create more liveable and sustainable places for future generations (Sabory *et al.* 2021). However, these practices are still rare in Southeast Asia, especially in a developing country like Indonesia. Excess runoff which can cause flooding decreased water quality, and excessive water use is a critical issue nowadays. Yet, the applicability of LID for this kind of country is still in question and needs to be explored. Moreover, there are so many obstacles which not in line with the sustainable goals (Morita *et al.* 2020). Therefore, this study aims to highlight the applicability of LID's usage in Indonesia by reviewing the relevance between the LID approach with Indonesia's current conditions.

2. LID OVERVIEW

2.1. Definition and type of LID

LID is a sustainable development approach aimed at minimizing the negative effects of human activities on the environment (Liu *et al.* 2021). It is a holistic and integrated approach to land use planning and design that emphasizes the use of natural systems and processes to manage stormwater (Li *et al.* 2019b), conserve energy (Miao *et al.* 2019), and protect the environment (Shafique & Kim 2018). This system promotes sustainable land use and development by reducing the amount of runoff and pollutants entering local water bodies (Yang & Dong 2021), improving water quality, and reducing flood risk (Li *et al.* 2019a). By incorporating LID principles, communities can create more sustainable, resilient, and livable environments for their residents (Anguelovski *et al.* 2019). Common LID techniques include RB, BR, and PP (Huang *et al.* 2018). RB is a simple and effective way to collect, store, and reuse rainwater (Pereira Guimarães *et al.* 2021). By collecting runoff from roofs, RB provides a source of water for landscaping (Tamaddun *et al.* 2018), gardening (Hamilton *et al.* 2018), and other non-potable uses (Andavar *et al.* 2020). BR is a type of stormwater management that uses vegetation, soil, and other natural components to filter pollutants and control stormwater runoff (Goh *et al.* 2019). BR systems are designed to mock natural processes such as infiltration and filtration to decrease contaminants from effluents before they are released into the environment (Galleto Jr. *et al.* 2022). Unlike traditional pavement such as concrete and asphalt, PP is a type of paving material that allows water to pass through (Ciriminna *et al.* 2022). These patches also have aesthetic and functional benefits (Zhu *et al.* 2021), such as the reduction of the heat island effect (Vujovic *et al.* 2021) and the improvement of drainage (Lu *et al.* 2019).

2.2. The differences between LID and conventional drainage

There are several differences between LID and conventional drainage systems, like an approach, scale, management, ability to diminish contaminants, and social and aesthetic aspects. LID is a holistic and integrated approach to stormwater management aimed at mimicking natural systems and processes. Traditional drainage systems, on the other hand, rely on infrastructure such as pipes and reservoirs to control stormwater runoff (Wu 2021). LID practices are small and decentralized, whereas traditional drainage systems are often large and centralized (Zhai *et al.* 2021). Stormwater management relies on natural systems, whereas typical drainage systems depend on engineered solutions (Lashford *et al.* 2019). They are also designed to erase contaminants, while conventional drainage systems typically do not remove contaminants from drains (Taguchi *et al.* 2020), and even can escalate the concentration of pollutants (Olds *et al.* 2018). LID often provide aesthetic and social benefits, such as green spaces (Darnthamrongkul & Mozingo 2020), community gardens (Mukherjee & Takara 2018), and educational opportunities (Kim 2019), conversely, conventional drainage systems typically have limited aesthetic and social benefits.

2.3. How LIDs work

LID can shrink stormwater runoff and contaminants through infiltration, filtration, evapotranspiration, and decentralized management (Wendling & Holt 2020). Practices such as BR and PP infiltrate water into the soil, lower the runoff rate, and filter contaminants (Chen *et al.* 2019). The nature filtration process can wipe out the number of contaminants entering the catchment. Filtration happened because of the existence of vegetation, soil, and other natural components (Mohanty *et al.* 2018). This system also promotes evapotranspiration, the process by which water is absorbed by plants and released into the atmosphere (Rodríguez-Sinobas *et al.* 2018). LID is decentralized, which means closer to the source, thus, this strategy work as runoff and pollutants source control (Van Steenbergen & Tuinhof 2021).

3. LID PERFORMANCE

3.1. Runoff volume and pollution reduction

Stormwater can contain different types of contaminants. The type, concentration, location, duration, and severity of the precipitation event all affect the amount of a certain pollutant in stormwater runoff (Mamun *et al.* 2020; Iqbal *et al.* 2022a). Stormwater runoff can contain high levels of BOD and COD due to the presence of contaminants such as oils, greases, pesticides, fertilizers, and other chemicals (López 2018). Additionally, it may also contain TP and TN as a consequence of the presence of contaminants such as fertilizers, sewage, and other waste products (Hager *et al.* 2019). Three typical metals detected in stormwater runoff are Cu, Pb, and Zn (Xiong *et al.* 2021). There are found in rainwater runoff from sources such as brakes, exhaust, tire wear, industrial processes, and paints (Müller *et al.* 2020).

The LID approaches RB, BR, and PP are made to regulate stormwater runoff and lessen the amount and contaminants it transports (Table 1). In order to reduce the quantity of runoff that would otherwise enter the drainage system, RB gathers and stores rainwater from rooftops for later use (EL-Nwsany *et al.* 2019). BR even have better performance in reducing metal pollutant due to the biochemical process, just like PP. Even so, PP shows relatively less effectiveness to eliminate BOD and COD (Jiang *et al.* 2015).

3.2. Water reuse potential

These RB, BR, and PP techniques are effective in reducing runoff volume. Since LID can be integrated with water treatment systems such as filtration, adsorption, absorption, and bioremediation, they can also provide additional benefits, such as improving water quality (Mehmood *et al.* 2021). These benefits can be substantial, including cost savings (Li *et al.* 2019b) and reduced environmental impact (Wang *et al.* 2020). The after-treatment water can be used for non-potable purposes such as irrigation, cleaning, and toilet flushing. LID use in cities, such as RB, can supplement dam water supply during droughts (Coombes & Barry 2008). Based on Marinoski *et al.* (2018), the potential for potable water in Brazil employing RB was 4,900 L/month water savings, which is a large 42.9% water savings. This potential can control water usage and the strain on municipal water supply systems, along with potentially reducing water bills (Table 2). Nevertheless, the optimal storage capacity should be explored case by case, and this would involve the actual number of users in each single-family information, as well as the water demand pattern (Freni & Liuzzo 2019).

3.3. LID limitation

The performance of LID in stormwater mitigation is determined by various factors, including the type of LID technology employed (Talebzadeh *et al.* 2021), design (Pour *et al.* 2020; Liu *et al.* 2021), and the implementation itself (city development, financial, and technological resources) (Ben-Daoud *et al.* 2022). Despite the benefits of RB, there are also some limitations to its use (Table 3). BR and PP can be expected to function effectively for an average of 20 years with proper maintenance (Tirpak *et al.* 2021b). Nevertheless, factors such as soil compaction, debris or mulch clogging, and damage from traffic can shorten the life of the system (DelGrosso *et al.* 2019). Thus, the question arises whether this LID can be used on an industrial or field scale (Cristiano *et al.* 2021).

4. INDONESIA CURRENT SITUATION

4.1. Current LID implementation in Indonesia

There is limited information about stormwater quality in Indonesia. However, it does not mean that the stormwater quality is all right. Due to rising urbanization, industrialization, and deforestation, stormwater quality in Indonesia is a problem (Bashir *et al.* 2020). These activities indicated an increase in pollutants such as sediment, oil, grease, heavy metals, and bacteria in

Table 1 | LID performance

LID practice	Reduction (%)									Note	Source
	Runoff	BOD	COD	TSS	TP	TN	Cu	Pb	Zn		
RB	12	–	–	–	–	–	–	–	–	Installation of large residential RB to reduce expected combined sewer volume	Ghodsi *et al.* (2021)
RB	18–40	–	–	–	–	–	–	–	–	RB ability depends on the installation site and RB storage volume	Oberascher *et al.* (2019)
RB	–	81	97	–	–	–	–	–	–	Using the combination of RB and green roof	Xu *et al.* (2020)
RB	–	–	–	40	77	75	–	–	–	Collecting and storing rainwater results in the amount of runoff that pollutes the stormwater system being reduced	Imteaz *et al.* (2022)
BR	48–96	–	–	–	–	–	–	–	–	By detaining and filtering runoff through vegetation, soil, and other materials	Shrestha *et al.* (2018)
BR	–	–	–	80	–	80.4	–	–	–	Using recyclable materials (shredded printed paper, coconut husk, cockle shell, tire crumb, and shredded newspaper) as potential additives	Goh *et al.* (2017)
BR	–	80	72	–	–	–	–	–	–	Using a cascaded bioretention system	Takaijudin *et al.* (2021)
BR	–	–	–	–	97	93	–	–	–	Natural chemical and biological processes	Goh *et al.* (2019)
BR	–	–	–	–	–	–	66	99	73	By chemical processes including adsorption, absorption, and remediation	Caldelas *et al.* (2021)
PP	30–65	–	–	–	–	–	–	–	–	Penetrate water through the surface and into the soil	Shafique *et al.* (2018)
PP	–	100	–	–	–	–	–	–	–	By physical filtering process	Kamali *et al.* (2017)
PP	–	–	–	–	–	–	79	92	88	Using interlocking concrete pavement (PICP) that built over a low-conductivity clay soil	Braswell *et al.* (2018)
PP	27	–	–	99.5	59	78	–	–	–	Using the cistern as a final polishing	Winston *et al.* (2020)

Table 2 | LID water reuse benefit

LID practice	Total treated area (m^2)	Benefit (US $)			Source
		Water saving	Irrigation	Groundwater recharge	
Combination of RB, BR soil filter, PP, green roofs, façade greening, tree drains, swales, trench, and ponds	183,624	125,332.07	–	129,388.75	Johnson & Geisendorf (2019)
Combination of PP, green space, and pond	35,613	1,233.73	5,996.12	4,581.17	Liu *et al.* (2016)

stormwater runoff (Sharma *et al.* 2022). This is also supported by using combined sewers which is still very common in Indonesia (Yustiani *et al.* 2018). This poor management of stormwater can also contribute to flooding and the degradation of water resources (Ashley *et al.* 2020), affecting the health and livelihoods of people and the environment (Locatelli *et al.* 2020). Regular monitoring of the quantity and quality of rainwater as guidance to design LID is believed to solve this problem.

Globally, LID practices have gained popularity as sustainable resource management and the impacts on it at the site or urban size have been extensively studied (Sui & van de Ven 2023). Many countries are adopting LID techniques to address problems related to flooding, water scarcity, water pollution, and to minimize the drawback of development on the environment (Xiang *et al.* 2019). According to Islam *et al.* (2021), the United States and China are ranked as the first and second most prominent countries in implementing and optimizing LID strategies. These are followed by Iran, Canada, South Korea, Australia, England, Italy, Singapore, and Taiwan. Although Indonesia has also conducted several studies on LID, the implementation of it still left behind (Kuller *et al.* 2022).

Table 3 | LID weaknesses

	Description	Source
RB		
Limited capacity	May not be effective in large rain events	Alamdari *et al.* (2018)
Pest harboring	Can harbor mosquitoes and other pests if not properly maintained	Uddin Sikder (2020)
Water quality	The quality of water stored in RB can be affected by roof runoff, sometimes it leading to an increase in heavy metals and other toxins	Lee *et al.* (2012)
BR and PP		
Climate dependence	Works most effectively in regions with moderate climates and adequate rainfall, and may be ineffective in regions with extreme temperature conditions	Dagenais *et al.* (2018) and Fowdar *et al.* (2021)
Large space requirement	Requires adequate space to be effective. Requires a significant amount of land area to be effective, which can be a challenge in densely populated or urban areas	Dai *et al.* (2020)
Soil type	May be ineffective in locations with high water tables or low permeability soils because they are unable to efficiently soak and retain stormwater runoff	Fan *et al.* (2021)
Cost	Maybe less appealing for some property owners or municipalities due to higher installation costs	Yang *et al.* (2020)
Clogging	The accumulation of silt, organic debris, or other contaminants in the soil or gravel layer can reduce its ability to function effectively due to: - heavy rainfall - poor maintenance - the presence of contaminants in the runoff	Beryani *et al.* (2021), Sanicola *et al.* (2018), Wang *et al.* (2022), and Yang *et al.* (2019)
Leaching	The process by which water and dissolved substances move downward through the soil and into the groundwater, bypassing the intended treatment processes, can contaminate groundwater and endanger both human health and the environment	Hernández-Crespo *et al.* (2019) and Talebzadeh *et al.* (2021)

Infiltration wells may be the only LID practices that have been implemented and already supported by the National and Sub-national governments. Despite the installation of 37,369 m^3 infiltration wells, flooding still occurs in Jakarta (Tempo 2021). This is because the infiltration wells are not suitable in downstream areas with low soil absorption capacity, such as in DKI Jakarta (Kompas 2021). The soil conditions in North and Central Jakarta are already saturated, which can lead to decreased effectiveness of the infiltration wells (JawaPos 2022). Currently, other LID practices like RB, BR, and PP in Indonesia are still at the modeling level and have not yet been applied (Widjojo & Agus 2018; Jokowinarno & Kusumastuti 2020). Considering that the modeling results show a good value, the use of RB, BR, and PP is worth trying.

4.2. LID challenges in Indonesia

4.2.1. High-density and complex drainage network

The complexity of Indonesia's drainage network is a result of rapid urbanization, high population growth, and inadequate infrastructure (Pambudi 2022). The increasing population has put extra pressure on the network, as more people depend on it for waste disposal (Surya *et al.* 2021). Indonesia's infrastructure is often insufficient to meet the demands of this growth, leading to an excessive and complex system of drains, sewers, and water treatment plants. The complexity is further exacerbated by the geographic and climatic variability across the country, which affects the design and management of the network (Malawani *et al.* 2021). For instance, some regions may experience heavy rainfall while others may face drought, which can affect the availability and feasibility of implementing LID installations (Pour *et al.* 2020). The densely populated areas with complex drainage networks can also limit the available space for installation due to interference with existing infrastructure such as underground pipes and culverts, making it challenging to integrate LID solutions into the existing networks (Kozak *et al.* 2020). Integrating LID installations into complex drainage networks requires careful planning and design to ensure that they function together effectively, adding time, cost, and complexity to the design and build process.

4.2.2. Combined sewer

Combined sewers in Indonesia are designed to carry both sanitary wastewater and stormwater runoff in the same conduit (Fithra *et al.* 2019) as shown in Figure 1. They are common in suburban areas where the separate sanitary and stormwater system is not yet a public concern. However, the use of combined sewers can pose some challenges, as the systems are often unable to handle the increased volume of water that can occur during heavy rainfall events (Botturi *et al.* 2021). This can result in the water volume exceeding the capacity of the pipes and causing overflows, which discharge untreated sewage and stormwater into nearby bodies of water, posing risks to public health and the environment (Davis *et al.* 2022). The installation of LID in this type of location will add to the complexity of the work, as overflows contain pollutants such as sediment (Rózsa *et al.* 2020). The presence of sediment can cause clogging of the BR and PP media, leading to a decrease in the performance of LID and making it less effective in reducing runoff volume and pollutants, as well as infiltrating water into the soil. As a result, maintenance of LID can become challenging and requires regular cleaning and monitoring (Goh *et al.* 2019). This process can be more expensive than LID in an ideal location, especially for RB, as tanks with highly polluted water inlets need more treatment to ensure that stored water reserves are safe for future use (Oberascher *et al.* 2019).

4.2.3. Soil type

In Indonesia, the soil types vary greatly and range from sandy to clayey, each of which poses different challenges for implementing LID practices. Sandy soil has a low water-holding capacity and dries out quickly (Spraakman & Drake 2021). This can pose problems for practices such as BR, which relies on plants to absorb and filter stormwater. According to Ali *et al.* (2021), these practices may not provide enough moisture for plant growth or effectively filter pollutants from the water in sandy soil. On the other hand, clayey soil has low permeability and can cause clogging and leaching (Goh *et al.* 2019). This leads to frequent maintenance, which could burden the time and cost for communities and industries. Furthermore, the type of plants used in LID practices should be chosen carefully to avoid overburdening the soil and negatively impacting its ability to absorb water, as clayey soil can easily become saturated. Clayey soil is also prone to cracking, which creates pathways for pollutants to reach the groundwater. Based on Wardoyo *et al.* (2019), 20 million hectares of land area in Indonesia is classified as clayey.

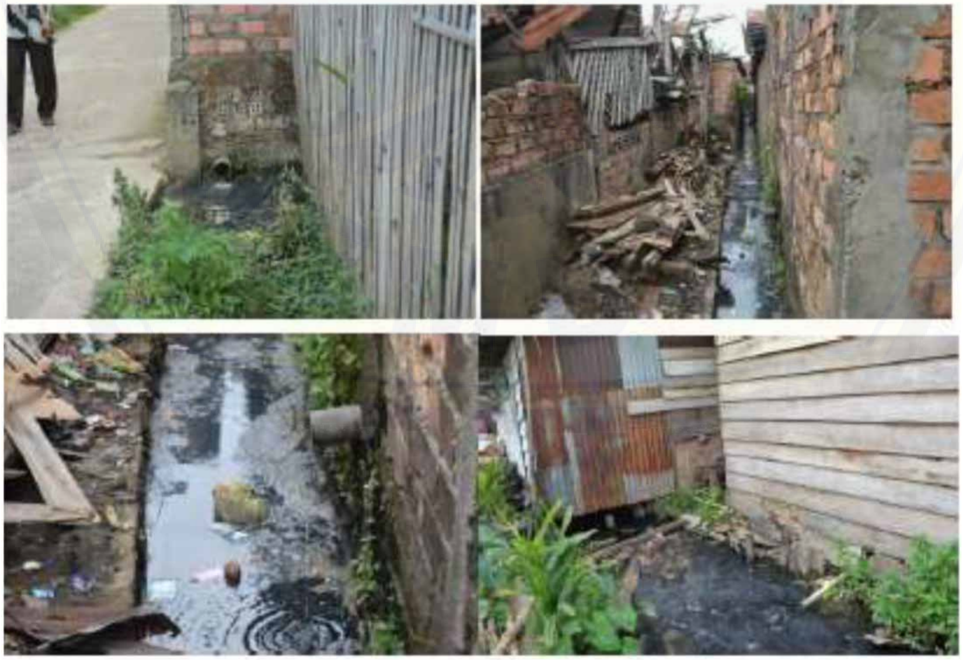


Figure 1 | Combine sewer in Palembang, Indonesia (Rachman 2020).

4.2.4. High-density and irregular housing layout

In Indonesia, residential areas are divided into two types: *permukiman* and *perumahan*. Typically, *perumahan* have better-organized patterns, while *permukiman* tend to be disorganized (Figure 2). The very dense and cluttered housing arrangements in permukiman, where walls are directly adjacent to one another, leave no space for the installation of BR and RB on a per-house basis. Although RB requires less land than BR, both still need a certain amount of space (Lin 2023). RB is typically installed near the downspout of a gutter system to collect and store rainwater for later use (Torres *et al.* 2020). However, with an irregular roof pattern, connecting the gutter to the communal RB tank becomes complicated, due to the complexity of the gutter network. This can result in the stored tank not being located in a convenient or accessible area (Hakim & Islam 2022). Therefore, PP might be the ideal solution to this problem. The PP or in the form of a permeable road can reduce part of surface runoff and flood peak and can delay peak time (Zhu *et al.* 2019a).

4.2.5. Community social-economy characteristic

The main water problems are flooding in the rainy season (Fitri *et al.* 2021) and depletion of clean water availability in the dry season (Taufik *et al.* 2022) in Indonesia, while the issue of stormwater pollution is still neglected. The tendency to fully utilize the land for housing construction without leaving space for vegetation can lead to increased impermeable surfaces and increased runoff during rain. Additionally, the heavy reliance on groundwater as the sole source of water for daily needs can result in environmental and economic problems, such as declining groundwater levels and reduced groundwater reserves (Odeh *et al.* 2019). Indonesian have traditionally relied on the government to address these problems, which the government has attempted to do through the implementation of technical solutions, such as drainage and distribution pipes. However, in rural areas, there is often a lack of awareness and resources to support environmentally friendly and sustainable solutions like LID. This is because of limited access to information, political and bureaucratic barriers, funding, and a limited understanding of the long-term benefits of LID. Additionally, poverty can lead to a focus on immediate needs, making it challenging for residents to prioritize investments in LID practices. This lack of support for LID initiatives may also be seen as a low priority for governments and other organizations that allocate funding and resources. Providing subsidies to encourage public installation can motivate communities to use LIDs like RB to meet their water needs (Lani *et al.* 2018).

4.2.6. Affordability and cost

The cost of installing RB, BR, and PP can vary greatly based on various factors such as the size, complexity of the system, materials used, local labor, and transportation costs. RB is the most affordable option among the three, due to the different components used in each system, where RB only requires a storage tank, whereas PP and BR require additional materials as shown in Tables 4 and 5. However, the actual cost of installation will depend on the local market conditions, the complexity of the installation process, and the specific design of the system (Liang *et al.* 2019). The integration of LID systems into residential properties can increase the overall construction cost, leading to higher housing prices (Wang *et al.* 2020), especially in the *perumahan* area. The developers may also face new challenges in designing and integrating LID into their properties, leading to further cost implications. This can make properties less affordable for Indonesian.

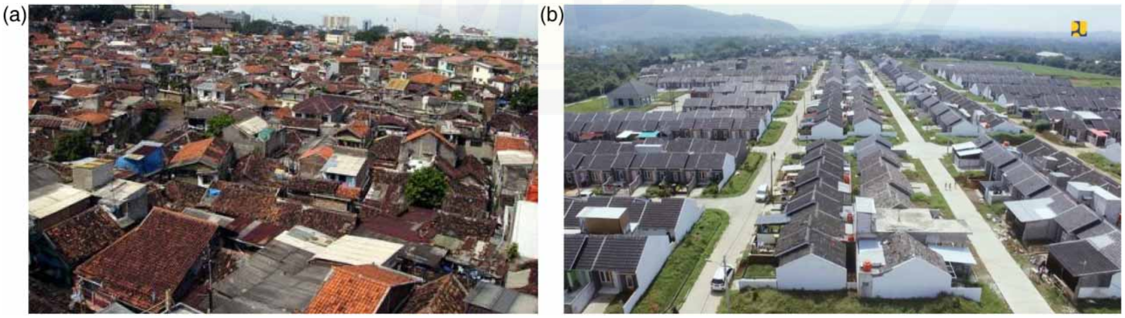


Figure 2 | *Permukiman* (a) and *perumahan* (b) layout (Medan City's Spatial Planning Department 2016; Ministry of Public Works and Housing 2020).

Table 4 | LID construction components

Components	LID practices RB	BR	PP
Plant	–	√	–
Gravel	–	√	√
Soil/sand	–	√	√
Excavation	–	√	√
Filter fabric	–	–	√
Pavement	–	–	√
Rainwater barrel	√	–	–
Pipe	√	–	√
Disposal	–	√	√

Source: Joshi *et al.* (2021).

Table 5 | Cost of construction, operational, and maintenance of LID

Construction cost (US$/m^2)			Annual operational and maintaining cost (US$/m^2)			
RB	BR	PP	RB	BR	PP	Source
6.71–8.59	–	75–150	0.077	–	1.01	Xie *et al.* (2017)
–	320.97	52.97	–	1.28	0.00	Johnson & Geisendorf (2019)
–	–	50.71–77.29	–	–	1.01–1.57	Yang *et al.* (2020)
–	–	28–150	–	–	0.90	Mei *et al.* (2018)
–	76.5–224	58–72	–	518–544*	13–109*	Chui *et al.* (2016)

Note: *Total O&M cost for 30 years life cycle.

4.2.7. Regulation and policy

The regulations regarding the implementation of urban drainage in Indonesia are outlined in the Ministerial Regulation of the Ministry of Public Works and Public Housing No. 12/PRT/M/2014. This regulation also discusses how public and private participation is needed to support the sustainable drainage program, starting from planning, construction implementation, operation, and maintenance as well as monitoring and evaluation. In some areas, there are also regional regulations, such as the Sumbawa Regency Regional Regulation No.18 of 2018 and the DKI Jakarta Governor Regulation No.109 of 2021. However, the meaning of sustainable drainage is limited to infiltration wells. Whereas, as explained in Section 4.1, infiltration wells are not necessarily suitable for application in all regions in Indonesia. Therefore, it is necessary to develop policies, regulations, laws, and manuals regarding the application of LIDs such as RB, BR, and PP, both at the national and sub-national scales. This can lead to consistencies in the LID implementation among stakeholders (Esmail & Suleiman 2020). Specially to regulate the informal sector, such as industry, which dominates in Indonesia. Yet, its existence is influenced by regional priority funds and programs. In the government sector, urban drainage planning and implementation does not have a separate source of funding from other nomenclature. Thus, even though there are clear regulations and organizational structures, without secured funding, LID will remain only a philosophy.

4.3. Suggestion

Based on the challenges faced in Indonesia due to its social, economic, and physical characteristics, specific strategies for LID implementation at the site level are necessary. It is important to conduct a pre-assessment of the drainage dimensions and distribution in built-up areas to aid in LID planning. By determining the dimensions and locations of drainage channels and pipes, potential damage during LID construction can be avoided, so traditional drainage and LID approaches can function effectively together (Goncalves *et al.* 2018). Usually, RB is suited to individual or existing buildings (Zabidi *et al.* 2020), however in highly populated areas with limited land, a communal system may be a feasible solution despite the challenges. The selection of suitable filtration media is also important, as drainage channels carry pollutants from both stormwater and domestic wastewater (Hoban & Gambirazio 2021). The filtration media can be selected based on the level of contaminants present (Tirpak *et al.* 2021a) and can include plants, gravel, activated carbon, or a combination of these options (Al *et al.* 2017). Research on phytoremediation has been conducted in Indonesia, and several plant species, including *Chrysopongon zizanoides L.* (Rahmawan *et al.* 2019), *Acanthus ilicifolius* (Intan Fatiha *et al.* 2020), *Pandanus amaryllifolius Roxb.* (Ambardini *et al.* 2020), *Actinoscirpus grossus*, and *Thypa angustifolia* L. (Mirwan & Puspita 2021) can be used as filtration media because of their ability to reduce pollutants and survive in both dry and wet seasons.

The correlation between organic matter and porosity in soil indicates that adding organic matter to sandy soil helps maintain a suitable environment for plants in BR practices (Spraakman & Drake 2021). Thus, basically, sandy soil is more suitable for PP practices than RB, since PP uses gravel or soil as the bottom layer. In clayey soil with low permeability, soil modification using biopolymers (Sujatha *et al.* 2020) or soil consolidation (Cheng *et al.* 2020), may be necessary to improve permeability for BR practices. Increasing PP thickness based on rainfall intensity also can increase the effectiveness of PP in clayey soil (Iqbal *et al.* 2022b). In general, any LID can be applied in clayey soil, but the use of BR needs to consider the type of plants so the plants did not burden the performance of the soil in absorbing water, given that clayey soil is saturated easily (Tang *et al.* 2021). RB which is stored above ground has no issues with soil characteristics because it solely captures water from the roof. However, with underground tanks, unstable or prone to erosion soil could compromise the RB's stability, causing it to tip over or become damaged. It is also critical to ensure that the surrounding region is having limited contaminants such as pesticides or other chemicals (Hamilton *et al.* 2018). To overcome this situation, which is always found in the area with combined sewers, the use of a filter device is necessary (Chu 2021). However, RB sounds to be the most convenient and less costly option to start stormwater management and utilization in the community, public infrastructure, and informal sector. Meanwhile, BR and PP with perfunctory planning will cause problems when these two practices experience clogging and leaching, which can be time and cost prohibitive. However, the use of Permeable Concrete Interlocking Pavement (PCIP) (Xu *et al.* 2022) and Zero Additional Maintenance approach (ZAM) (Prodanovic *et al.* 2022) can improve the performance of PP and BR in reducing maintenance prices.

Clear rules and regulations are needed in the use of LID, especially RB which have the potential to be applied, such as who is obliged to establish and manage RB, how and where RB is established, house prices after LID application, and the provision possibility of financial incentives such as subsidies, grants, tax exemptions, supports and funds, and income-producing activities (Hindiyeh *et al.* 2021). Evaluation after LID implementation is also important to address any problems that may arise (Novaes & Marques 2022). Moreover, a technique such as BR and PP may be also regulated, especially if they are integrated with communal management such as retention ponds (Beckingham *et al.* 2019). Community-based LID regulations are applicable for education and public awareness, as well as to increase community participation in planning, operating, and maintaining LID infrastructure (Ye *et al.* 2020). The central government should provide clear guidance and support to local governments for the implementation of sustainable drainage systems, taking into account the unique social, economic, and physical characteristics of each region. This includes providing a mandate for local governments to develop their regulations and guidelines for the implementation of sustainable drainage systems, based on the specific needs and conditions of their respective locations. This will ensure that the implementation of sustainable drainage systems is tailored to the local context and is more effective in addressing the challenges of managing runoff and promoting sustainable water management practices. Furthermore, involving local governments in the planning and implementation process will increase their capacity to manage and maintain sustainable drainage systems and foster greater community engagement and ownership. This will also help to build resilience and adaptability in the face of changing weather patterns and climate-related impacts. Therefore, based on the suggestion above, the priority LID usage is summarized in Table 6.

5. CONCLUSION

LID is a sustainable land-use and planning approach aimed at reducing the adverse impacts of development on the natural environment. Adopting LID practices, such as RB, BR, and PP communities can enhance water resources, conserve the environment, and create more livable and sustainable communities. LID has been successful in managing stormwater and promoting water reuse globally. However, its applicability in developing countries, such as Indonesia, is still under investigation and requires further exploration. The implementation of LID in these countries may face numerous challenges that

Table 6 | Priority of suitable LID usage in Indonesia

Challenges	Priority of suitable LID usage
High-density and complex network drainage	PP on the sidewalks and parking lots > individual or communal RB
Combine sewer	Phytoremediation by utilizing BR > RB with a filter device
Soil type	
Sandy	PP > RB
Clayey	RB > PP > BR with specific plant and based on local climate condition
High-density and irregular housing layout	PP on the sidewalks > BR on remaining land > Communal RB
Community social-economy characteristic	RB > PP > BR
Affordability and cost	RB > PP > BR
Regulation and policy	RB > PP > BR

Note: (>) symbolizes as better than.

are not aligned with sustainable goals, such as high-density and complex drainage networks, the use of combined sewer systems, clayey soil types, high-density and irregular housing layouts, community socio-economic characteristics, affordability and cost, as well as regulations and policies.

Despite these obstacles, LID can be implemented in Indonesia with proper planning. This requires site-specific strategies due to the unique social, economic, and physical characteristics of each location. A pre-assessment of drainage dimensions and distribution in built-up areas is crucial for effective LID planning, in which the selection of suitable filtration media should also be considered based on the level of contaminants present. In terms of feasibility and cost, RB is the best starting point for stormwater management and utilization programs in communities, public infrastructure, and industries. Clear rules and regulations are necessary for the proper implementation of LID, whereas the central government should provide clear guidance and support to local governments, especially if the LIDs are integrated with communal management. Community-based LID is also highly recommended to increase sustainable education and public awareness. By involving the community in the planning, operation, and maintenance of LID infrastructure, the community can become more aware of the importance of LID, and it can be optimized. This article serves as a guide in considering the implementation of LID in Indonesia and other countries with similar characteristics.

DATA AVAILABILITY STATEMENT

All relevant data are available from an online repository or repositories.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Al, A., Voijant, B., Lingkungan, D. T., Teknologi, I., Nopember, S. & Hakim, A. R. 2017 Design of silica sand filter media and activated carbon filter as polluted groundwater treatment technology in the former Keputih landfill site. *J. Purifikasi* **21** (1). https://doi.org/10.12962/j25983806.v21.i1.431.

Alamdari, N., Sample, D. J., Liu, J. & Ross, A. 2018 Assessing climate change impacts on the reliability of rainwater harvesting systems. *Resour. Conserv. Recycl.* **132**, 178–189. https://doi.org/10.1016/j.resconrec.2017.12.013.

Ali, W., Takaijudin, H., Yusof, K. W., Osman, M. & Abdurrasheed, A. S. 2021 The common approaches of nitrogen removal in bioretention system. *Sustainability* **13** (5), 1–17. https://doi.org/10.3390/su13052575.

Ambardini, S., Ahmad, S. W. & Amir, A. 2020 Fitoremediasi Limbah Laundry kota Kendari Menggunakan Tanaman Pandan Wangi (*Pandanus amaryllifolius* Roxb.). *BioWallacea J. Penelit. Biol. (J. Biol. Res.)* **7**, 1163–1175.

Andavar, V., Ali, B. J. & Ali, S. A. 2020 'Rainwater for water scarcity management: an experience of Woldia University (Ethiopia). *J. Bus. Econ. Environ. Stud.* **10** (4), 29–34. https://doi.org/10.13106/jbees.2020.vol10.no4.29.

Anguelovski, I., Irazábal-Zurita, C. & Connolly, J. J. T. 2019 Grabbed urban landscapes: socio-spatial tensions in green infrastructure planning in Medellín. *Int. J. Urban Reg. Res.* **43** (1), 133–156. https://doi.org/10.1111/1468-2427.12725.

Ashley, R., Gersonius, B. & Horton, B. 2020 Managing flooding: from a problem to an opportunity. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **378** (2168). https://doi.org/10.1098/rsta.2019.0214.

Bashir, I., Lone, F. A., Bhat, R. A., Mir, S. A., Dar, Z. A. & Dar, S. A. 2020 Concerns and threats of contamination on aquatic ecosystems. In: *Bioremediation and Biotechnology: Sustainable Approaches to Pollution Degradation*. Springer.

Batalini de Macedo, M., Nóbrega Gomes Júnior, M., Pereira de Oliveira, T. R., Giacomoni, M. H., Imani, M., Zhang, K., Ambrogi Ferreira do Lago, C. & Mendiondo, E. M. 2022 Low impact development practices in the context of United Nations Sustainable Development Goals: a new concept, lessons learned and challenges. *Crit. Rev. Environ. Sci. Technol.* **52** (14), 2538–2581. https://doi.org/10.1080/10643389.2021.1886889.

Beckingham, B., Callahan, T. & Vulava, V. 2019 Stormwater ponds in the southeastern U.S. coastal plain: hydrogeology, contaminant fate, and the need for a social-ecological framework. *Front. Environ. Sci.* **7**. https://doi.org/10.3389/fenvs.2019.00117.

Ben-Daoud, A., Ben-Daoud, M., Moroşanu, G. A. & M'Rabet, S. 2022 The use of low impact development technologies in the attenuation of flood flows in an urban area: Settat city (Morocco) as a case. *Environ. Challenges* **6**. https://doi.org/10.1016/j.envc.2021.100403.

Beryani, A., Goldstein, A., Al-Rubaei, A. M., Viklander, M., Hunt, W. F. & Blecken, G. T. 2021 Survey of the operational status of twenty-six urban stormwater biofilter facilities in Sweden. *J. Environ. Manage.* **297**, 113375. https://doi.org/10.1016/j.jenvman.2021.113375.

Botturi, A., Ozbayram, E. G., Tondera, K., Gilbert, N. I., Rouault, P., Caradot, N., Gutierrez, O., Daneshgar, S., Frison, N., Akyol, Ç., Foglia, A., Eusebi, A. L. & Fatone, F. 2021 Combined sewer overflows: a critical review on best practice and innovative solutions to mitigate impacts on environment and human health. *Crit. Rev. Environ. Sci. Technol.* **51** (15), 1585–1618. https://doi.org/10.1080/10643389.2020.1757957.

Braswell, A. S., Winston, R. J. & Hunt, W. F. 2018 Hydrologic and water quality performance of permeable pavement with internal water storage over a clay soil in Durham, North Carolina. *J. Environ. Manage.* **224**, 277–287. https://doi.org/10.1016/j.jenvman.2018.07.040.

Caldelas, C., Gurí, R., Araus, J. L. & Sorolla, A. 2021 Effect of ZnO nanoparticles on Zn, Cu, and Pb dissolution in a green bioretention system for urban stormwater remediation. *Chemosphere* **282**, 131045. https://doi.org/10.1016/j.chemosphere.2021.131045.

Chen, J., Liu, Y., Gitau, M. W., Engel, B. A., Flanagan, D. C. & Harbor, J. M. 2019 Evaluation of the effectiveness of green infrastructure on hydrology and water quality in a combined sewer overflow community. *Sci. Total Environ.* **665**, 69–79. https://doi.org/10.1016/j.scitotenv.2019.01.416.

Cheng, G., Zhu, H. H., Wen, Y. N., Shi, B. & Gao, L. 2020 Experimental investigation of consolidation properties of nano-bentonite mixed clayey soil. *Sustainability* **12** (2). https://doi.org/10.3390/su12020459.

Chu, S. 2021 Study on comprehensive utilization of water resource environment in water-saving design of buildings. *Acad. J. Environ. Earth Sci.* **3** (3), 47–50. https://doi.org/10.25236/ajee.2021.030310.

Chui, T. F. M., Liu, X. & Zhan, W. 2016 Assessing cost-effectiveness of specific LID practice designs in response to large storm events. *J. Hydrol.* **533**, 353–364. https://doi.org/10.1016/j.jhydrol.2015.12.011.

Ciriminna, D., Ferreri, G. B., Noto, L. V. & Celauro, C. 2022 Numerical comparison of the hydrological response of different permeable pavements in urban area. *Sustainability* **14** (9). https://doi.org/10.3390/su14095704.

Coombes, P. J. & Barry, M. E. 2008 The relative efficiency of water supply catchments and rainwater tanks in cities subject to variable climate and the potential for climate change. *Aust. J. Water Resour.* **12** (1), 85–100. https://doi.org/10.1080/13241583.2008.11465337.

Cristiano, E., Farris, S., Deidda, R. & Viola, F. 2021 Comparison of blue-green solutions for urban flood mitigation: a multi-city large-scale analysis. *PLoS ONE* **16**, 1–15. https://doi.org/10.1371/journal.pone.0246429.

Dagenais, D., Brisson, J. & Fletcher, T. D. 2018 The role of plants in bioretention systems: does the science underpin current guidance? *Ecol. Eng.* **120**, 532–545. https://doi.org/10.1016/j.ecoleng.2018.07.007.

Dai, Y., Jiang, J., Gu, X., Zhao, Y. & Ni, F. 2020 Sustainable urban street comprising permeable pavement and bioretention facilities: a practice. *Sustainability* **12** (19). https://doi.org/10.3390/su12198288.

Darnthamrongkul, W. & Mozingo, L. A. 2020 Challenging anthropocentric stormwater management: advancing legislation for environmental sustainability in the United States. *Water Secur.* **10**, 100064. https://doi.org/10.1016/j.wasec.2020.100064.

Davis, L. J., Milligan, R., Stauber, C. E., Jelks, N. O., Casanova, L. & Ledford, S. H. 2022 Environmental injustice and *Escherichia coli* in urban streams: potential for community-led response. *Wiley Interdiscip. Rev. Water* **9** (3). https://doi.org/10.1002/wat2.1583.

DelGrosso, Z. L., Hodges, C. C. & Dymond, R. L. 2019 Identifying key factors for implementation and maintenance of green stormwater infrastructure. *J. Sustain. Water Built Environ.* **5** (3), 1–12. https://doi.org/10.1061/jswbay.0000878.

Dong, F., Zhang, Z., Liu, C., Zou, R., Liu, Y. & Guo, H. 2020 Towards efficient low impact development: a multi-scale simulation-optimization approach for nutrient removal at the urban watershed. *J. Clean. Prod.* **269**, 122295. https://doi.org/10.1016/j.jclepro.2020.122295.

EL-Nwsany, R. I., Maarouf, I. & Abd el-Aal, W. 2019 Water management as a vital factor for a sustainable school. *Alexandria Eng. J.* **58** (1), 303–313. https://doi.org/10.1016/j.aej.2018.12.012.

Esmail, B. A. & Suleiman, L. 2020 Analyzing evidence of sustainable urban water management systems: a review through the lenses of sociotechnical transitions. *Sustainability* **12** (11). https://doi.org/10.3390/su12114481.

Fan, G., Ning, R., Huang, K., Wang, S., You, Y., Du, B. & Yan, Z. 2021 Hydrologic characteristics and nitrogen removal performance by different formulated soil medium of bioretention system. *J. Clean. Prod.* **290**, 125873. https://doi.org/10.1016/j.jclepro.2021.125873.

Fithra, H., Olivia, S. & Siska, D. 2019 Analysis reducing slum settlement by road improvement (A case study: Jawa Lama Village Village, Lhokseumawe, Aceh-Indonesia). *Aceh Int. J. Sci. Technol.* **8** (1), 20–28. https://doi.org/10.13170/aijst.8.1.12370.

Fitri, A., Hadie, M. S. N., Agustina, A., Pratiwi, D., Susarman, S., Pramita, G. & Ali, H. R. 2021 Analyses of flood peak discharge in Cimadur river basin, Banten Province, Indonesia. *E3S Web Conf.* **331**, 0–5. https://doi.org/10.1051/e3sconf/202133108006.

Fowdar, H., Payne, E., Schang, C., Zhang, K., Deletic, A. & McCarthy, D. 2021 How well do stormwater green infrastructure respond to changing climatic conditions? *J. Hydrol.* **603** (PA), 126887. https://doi.org/10.1016/j.jhydrol.2021.126887.

Freni, G. & Liuzzo, L. 2019 Effectiveness of rainwater harvesting systems for flood reduction in residential urban areas. *Water (Switzerland)* **11** (7). https://doi.org/10.3390/w11071389.

Galleto Jr, F. A., ., Cabatuan, M. K., Africa, A. D. M., Maniquiz-redillas, M. C., Navaluna, J. M., Herrera, J. C. Q., Ubando, A. T., Culaba, A. B. & Redillas, M. C. F. R. 2022 Characterization model using fuzzy rough set theory. *Water (Switzerland)* **14** (13), 2037. https://doi.org/10.3390/w14132037.

Ghodsi, S. H., Zhu, Z., Gheith, H., Rabideau, A. J., Torres, M. N. & Meindl, K. 2021 Modeling the effectiveness of rain barrels, cisterns, and downspout disconnections for reducing combined sewer overflows in a city-scale watershed. *Water Resour. Manage.* **35** (9), 2895–2908. https://doi.org/10.1007/s11269-021-02875-7.

Gispert, M. Í., Hernández, M. A. A., Climent, E. L. & Flores, M. F. T. 2018 Rainwater harvesting as a drinking water option for Mexico city. *Sustainability* **10** (11), 1–13. https://doi.org/10.3390/su10113890.

Goh, H. W., Zakaria, N. A., Lau, T. L., Foo, K. Y., Chang, C. K. & Leow, C. S. 2017 Mesocosm study of enhanced bioretention media in treating nutrient rich stormwater for mixed development area. *Urban Water J.* **14** (2), 134–142. https://doi.org/10.1080/1573062X.2015.1076861.

Goh, H. W., Lem, K. S., Azizan, N. A., Chang, C. K., Talei, A., Leow, C. S. & Zakaria, N. A. 2019 A review of bioretention components and nutrient removal under different climates – future directions for tropics. *Environ. Sci. Pollut. Res.* **26** (15), 14904–14919. https://doi.org/10.1007/s11356-019-05041-0.

Goncalves, M. L. R., Zischg, J., Rau, S., Sitzmann, M. & Rauch, W. 2018 Modeling the effects of introducing low impact development in a tropical city: a case study from Joinville, Brazil. *Sustainability* **10** (3), 728. https://doi.org/10.3390/su10030728.

Hager, J., Hu, G., Hewage, K. & Sadiq, R. 2019 Performance of low-impact development best management practices: a critical review. *Environ. Rev.* **27** (1), 17–42. https://doi.org/10.1139/er-2018-0048.

Hakim, S. S. & Islam, M. A. 2022 *Sustainable Water Technologies for Housing Rehabilitation in Coastal Bangladesh*. Khulna University Studies, pp. 817–831. https://doi.org/10.53808/kus.2022.icstem4ir.0144-se.

Hamilton, K. A., Parrish, K., Ahmed, W. & Haas, C. N. 2018 Assessment of water quality in roof-harvested rainwater barrels in Greater Philadelphia. *Water (Switzerland)* **10** (2), 92. https://doi.org/10.3390/w10020092.

Hernández-Crespo, C., Fernández-Gonzalvo, M., Martín, M. & Andrés-Doménech, I. 2019 Influence of rainfall intensity and pollution build-up levels on water quality and quantity response of permeable pavements. *Sci. Total Environ.* **684**, 303–313. https://doi.org/10.1016/j.scitotenv.2019.05.271.

Hindiyeh, M. Y., Matouq, M. & Eslamian, S. 2021 Rainwater harvesting policy issues in the MENA region: lessons learned, challenges, and sustainable recommendations. In: *Handbook of Water Harvesting and Conservation*. pp. 457–473. https://doi.org/10.1002/9781119478911.ch30.

Hoban, A. & Gambirazio, C. 2021 Bioretention performance: a review of field studies. *Aust. J. Water Resour.* **25** (2). https://doi.org/10.1080/13241583.2021.1984190.

Huang, C. L., Hsu, N. S., Liu, H. J. & Huang, Y. H. 2018 Optimization of low impact development layout designs for megacity flood mitigation. *J. Hydrol.* **564**, 542–558. https://doi.org/10.1016/j.jhydrol.2018.07.044.

Imteaz, M. A., Boulomytis, V. T. G., Yilmaz, A. G. & Shanableh, A. 2022 Water quality improvement through rainwater tanks: a review and simulation study. *Water (Switzerland)* **14** (9). https://doi.org/10.3390/w14091411.

Intan Fatiha, I., Mei Afifudin, A. F. & Irawan, R. 2020 Uji Kemampuan Awal *Acanthus ilicifolius* sebagai Fitoremediasi Limbah Detergen. In: *Seminar Nasional Biologi 5*. Departmen Biology, Faculty Sciences and Technology, UIN Sunan Gunung Djati, Bandung.

Iqbal, A., Rahman, M. M. & Beecham, S. 2022a Spatial analysis of the water harvesting potential of permeable pavements in Australia. *Sustainability* **14** (23). https://doi.org/10.3390/su142316282.

Iqbal, A., Rahman, M. M. & Beecham, S. 2022b Permeable pavements for flood control in Australia: spatial analysis of pavement design considering rainfall and soil data. *Sustainability* **14** (9). https://doi.org/10.3390/su14094970.

Ishaq, S., Hewage, K., Farooq, S. & Sadiq, R. 2019 State of provincial regulations and guidelines to promote low impact development (LID) alternatives across Canada: content analysis and comparative assessment. *J. Environ. Manage.* **235**, 389–402. https://doi.org/10.1016/j.jenvman.2019.01.074.

Islam, A., Hassini, S. & El-Dakhakhni, W. 2021 A systematic bibliometric review of optimization and resilience within low impact development stormwater management practices. *J. Hydrol.* **599**, 126457. https://doi.org/10.1016/j.jhydrol.2021.126457.

Jiang, W., Sha, A., Xiao, J., Li, Y. & Huang, Y. 2015 Experimental study on filtration effect and mechanism of pavement runoff in permeable asphalt pavement. *Constr. Build. Mater.* **100**, 102–110. https://doi.org/10.1016/j.conbuildmat.2015.09.055.

Johnson, D. & Geisendorf, S. 2019 Are neighborhood-level SUDS worth it ? An assessment of the economic value of sustainable urban drainage system scenarios using cost-benefit analyses. *Ecol. Econ.* **158**, 194–205. https://doi.org/10.1016/j.ecolecon.2018.12.024.

Jokowinarno, D. & Kusumastuti, D. I. 2020 Rainwater harvesting for flood peak reduction in way Awi Catchment, Indonesia. *Int. J. GEOMATE* **18** (70), 246–251.

Joshi, P., Leitão, J. P., Maurer, M. & Bach, P. M. 2021 Not all SuDS are created equal: impact of different approaches on combined sewer overflows. *Water Res.* **191**, 116780. https://doi.org/10.1016/j.watres.2020.116780.

Kamali, M., Delkash, M. & Tajrishy, M. 2017 Evaluation of permeable pavement responses to urban surface runoff. *J. Environ. Manage.* **187**, 43–53. https://doi.org/10.1016/j.jenvman.2016.11.027.

Kim, D. 2019 The multifunctional benefits of green infrastructure in community development: an analytical review based on 447 cases. *Sustainability*, 1–17. https://doi.org/10.3390/su11143917.

Kozak, D., Henderson, H., Mazarro, A. d. C., Rotbart, D. & Aradas, R. 2020 Blue-green infrastructure (BGI) in dense urban watersheds. The case of the Medrano stream basin (MSB) in Buenos Aires. *Sustainability* **12** (6). https://doi.org/10.3390/su12062163.

Kuller, M., Farrelly, M., Marthanty, D. R., Deletic, A. & Bach, P. M. 2022 Planning support systems for strategic implementation of nature-based solutions in the global south: current role and future potential in Indonesia. *Cities* **126**, 103693. https://doi.org/10.1016/j.cities.2022.103693.

Lani, N. H. M., Yusop, Z. & Syafiuddin, A. 2018 A review of rainwater harvesting in Malaysia: prospects and challenges. *Water (Switzerland)* **10** (4), 1–21. https://doi.org/10.3390/w10040506.

Lashford, C., Rubinato, M., Cai, Y., Hou, J., Abolfathi, S., Coupe, S., Charlesworth, S. & Tait, S. 2019 SuDS & sponge cities: a comparative analysis of the implementation of pluvial flood management in the UK and China. *Sustainability* **11** (213), 1–14. https://doi.org/10.3390/su11010213.

Lee, J. Y., Bak, G. & Han, M. 2012 Quality of roof-harvested rainwater – comparison of different roofing materials. *Environ. Pollut.* **162**, 422–429. https://doi.org/10.1016/j.envpol.2011.12.005.

Li, F., Yan, X. F. & Duan, H. F. 2019a Sustainable design of urban stormwater drainage systems by implementing detention tank and LID measures for flooding risk control and water quality management. *Water Resour. Manage.* **33** (9), 3271–3288. https://doi.org/10.1007/s11269-019-02300-0.

Li, Q., Wang, F., Yu, Y., Huang, Z., Li, M. & Guan, Y. 2019b Comprehensive performance evaluation of LID practices for the sponge city construction: a case study in Guangxi, China. *J. Environ. Manage.* **231**. https://doi.org/10.1016/j.jenvman.2018.10.024.

Liang, C. Y., You, G. J. Y. & Lee, H. Y. 2019 Investigating the effectiveness and optimal spatial arrangement of low-impact development facilities. *J. Hydrol.* **577**, 124008. https://doi.org/10.1016/j.jhydrol.2019.124008.

Liew, Y. S., Desa, S. M., Noh, M. N. M., Tan, M. L., Zakaria, N. A. & Chang, C. K. 2021 Assessing the effectiveness of mitigation strategies for flood risk reduction in the Segamat river basin, Malaysia. *Sustainability* **13** (6), 1–23. https://doi.org/10.3390/su13063286.

Lin, J. 2023 Efficacy of rain barrels and rain gardens to reduce urban pluvial flooding. *Res. Square*, 1–23.

Liu, W., Chen, W., Feng, Q., Peng, C. & Kang, P. 2016 Cost-benefit analysis of green infrastructures on community stormwater reduction and utilization: a case of Beijing, China. *Environ. Manage.* **58** (6), 1015–1026. https://doi.org/10.1007/s00267-016-0765-4.

Liu, T., Lawluvy, Y., Shi, Y. & Yap, P. S. 2021 *Low Impact Development (LID) Practices: A Review on Recent Developments, Challenges and Prospects. Water, Air, & Soil Pollution*. Springer International Publishing.

Locatelli, L., Russo, B., Acero Oliete, A., Carlos Sánchez Catalán, J., Martínez-Gomariz, E. & Martínez, M. 2020 Modeling of *E. coli* distribution for hazard assessment of bathing waters affected by combined sewer overflows. *Nat. Hazards Earth Syst. Sci.* **20** (5), 1219–1232. https://doi.org/10.5194/nhess-20-1219-2020.

López, H. 2018 *Performance Examination of Sustainable Urban Drainage Systems – A Multi-Criteria Analysis for the City of Gothenburg*. Chalmers University of Technology.

Lu, G., Liu, P., Wang, Y., Faßbender, S., Wang, D. & Oeser, M. 2019 Development of a sustainable pervious pavement material using recycled ceramic aggregate and bio-based polyurethane binder. *J. Clean. Prod.* **220**, 1052–1060. https://doi.org/10.1016/j.jclepro.2019.02.184.

Malawani, M. N., Lavigne, F., Gomez, C., Mutaqin, B. W. & Hadmoko, D. S. 2021 Review of local and global impacts of volcanic eruptions and disaster management practices: the Indonesian example. *Geosciences* **11** (3), 1–18. https://doi.org/10.3390/geosciences11030109.

Mamun, A. A., Shams, S. & Nuruzzaman, M. 2020 Review on uncertainty of the first-flush phenomenon in diffuse pollution control. *Appl. Water Sci.* **10** (1), 1–10. https://doi.org/10.1007/s13201-019-1127-1.

Marinoski, A. K., Rupp, R. F. & Ghisi, E. 2018 Environmental benefit analysis of strategies for potable water savings in residential buildings. *J. Environ. Manage.* **206**, 28–39. https://doi.org/10.1016/j.jenvman.2017.10.004.

Mehmood, T., Gaurav, G. K., Cheng, L., Klemeš, J. J., Usman, M., Bokhari, A. & Lu, J. 2021 A review on plant-microbial interactions, functions, mechanisms and emerging trends in bioretention system to improve multi-contaminated stormwater treatment. *J. Environ. Manage.* **294**. https://doi.org/10.1016/j.jenvman.2021.113108.

Mei, C., Liu, J., Wang, H., Yang, Z., Ding, X. & Shao, W. 2018 Integrated assessments of green infrastructure for flood mitigation to support robust decision-making for sponge city construction in an urbanized watershed. *Sci. Total Environ.* **639**. https://doi.org/10.1016/j.scitotenv.2018.05.199.

Miao, Z. T., Han, M. & Hashemi, S. 2019 The effect of successive low-impact development rainwater systems on peak flow reduction in residential areas of Shizhuang, China. *Environ. Earth Sci.* **78** (2), 1–12. https://doi.org/10.1007/s12665-018-8016-z.

Mirwan, M. & Puspita, I. 2021 FITOREMEDIASI LIMBAH LAUNDRY MENGGUNAKAN TANAMAN MENSIANG (*Actinoscirpus grossus*) DAN LEMBANG (*Thypa angustifolia* L.). *EnviroUS* **2** (1), 61–66. https://doi.org/10.33005/envirous.v2i1.69.

Mohammed, M. H., Zwain, H. M. & Hassan, W. H. 2022 Modeling the quality of sewage during the leaking of stormwater surface runoff to the sanitary sewer system using SWMM: a case study. *Aqua Water Infrastruct. Ecosyst. Soc.* **71** (1), 86–99. https://doi.org/10.2166/aqua.2021.227.

Mohanty, S. K., Valenca, R., Berger, A. W., Yu, I. K. M., Xiong, X., Saunders, T. M. & Tsang, D. C. W. 2018 Plenty of room for carbon on the ground: potential applications of biochar for stormwater treatment. *Sci. Total Environ.* **625**, 1644–1658. https://doi.org/10.1016/j.scitotenv.2018.01.037.

Mooers, E. W., Jamieson, R. C., Hayward, J. L., Drage, J. & Lake, C. B. 2018 Low-impact development effects on aquifer recharge using coupled surface and groundwater models. *J. Hydrol. Eng.* **23** (9), 1–11. https://doi.org/10.1061/(asce)he.1943-5584.0001682.

Morash, J., Wright, A., LeBleu, C., Meder, A., Kessler, R., Brantley, E. & Howe, J. 2019 Increasing sustainability of residential areas using rain gardens to improve pollutant capture, biodiversity and ecosystem resilience. *Sustainability* **11** (12). https://doi.org/10.3390/SU11123269.

Morita, K., Okitasari, M. & Masuda, H. 2020 Analysis of national and local governance systems to achieve the sustainable development goals: case studies of Japan and Indonesia. *Sustain. Sci.* **15** (1), 179–202. https://doi.org/10.1007/s11625-019-00739-z.

Mukherjee, M. & Takara, K. 2018 Urban green space as a countermeasure to increasing urban risk and the UGS-3CC resilience framework. *Int. J. Disaster Risk Reduct.* **28**. https://doi.org/10.1016/j.ijdrr.2018.01.027.

Müller, A., Österlund, H., Marsalek, J. & Viklander, M. 2020 The pollution conveyed by urban runoff: a review of sources. *Sci. Total Environ.* **709**, 136125. https://doi.org/10.1016/j.scitotenv.2019.136125.

Nguyen, T. T., Ngo, H. H., Guo, W., Wang, X. C., Ren, N., Li, G., Ding, J. & Liang, H. 2019 Implementation of a specific urban water management – Sponge City. *Sci. Total Environ.* **652**, 147–162. https://doi.org/10.1016/j.scitotenv.2018.10.168.

Novaes, C. & Marques, R. 2022 Public policy: urban stormwater in a paradigm shift, is it the end or just the beginning? *Water Sci. Technol.* **85** (9), 2652–2662. https://doi.org/10.2166/wst.2022.127.

Oberascher, M., Zischg, J., Palermo, S. A., Kinzel, C., Rauch, W. & Sitzenfrei, R. 2019 Smart rain barrels: advanced LID management through measurement and control. *Green Energy Technol., (Kerkez)*, 777–782. https://doi.org/10.1007/978-3-319-99867-1_134.

Odeh, T., Mohammad, A. H., Hussein, H., Ismail, M. & Almomani, T. 2019 Over-pumping of groundwater in Irbid governorate, northern Jordan: a conceptual model to analyze the effects of urbanization and agricultural activities on groundwater levels and salinity. *Environ. Earth Sci.* **78** (1), 1–12. https://doi.org/10.1007/s12665-018-8031-0.

Olds, H. T., Corsi, S. R., Dila, D. K., Halmo, K. M., Bootsma, J. & Mclellan, S. L. 2018 High levels of sewage contamination released from urban areas after storm events: a quantitative survey with sewage specific bacterial indicators. *PLoS Med.* **15** (7), 1–23. https://doi.org/10.1371/journal.pmed.1002614.

Pambudi, A. S. 2022 Problem of local floods and their relation to Bogor city drainage infrastructure system. *Indones. J. Appl. Res.* **3** (1), 10–22. https://doi.org/10.30997/ijar.v3i1.178.

Pereira Guimarães, M., Moredia Valek, A., Dessi, V. & Clementi, M. 2021 A simplified procedure to improve the usability of hydrodynamic modelling software in regenerative urban design. *J. Phys. Conf. Ser.* **2042** (1), 012063. https://doi.org/10.1088/1742-6596/2042/1/012063.

Pour, S. H., Wahab, A. K. A., Shahid, S., Asaduzzaman, M. & Dewan, A. 2020 Low impact development techniques to mitigate the impacts of climate-change-induced urban floods: current trends, issues and challenges. *Sustain. Cities Soc.* **62**, 102373. https://doi.org/10.1016/j.scs.2020.102373.

Prodanovic, V., Hatt, B., Fowdar, H., Al-Ameri, M. & Deletic, A. 2022 Zero additional maintenance stormwater biofilters: from laboratory testing to field implementation. *Blue-Green Syst.* **4** (2), 291–309. https://doi.org/10.2166/bgs.2022.030.

Rachman, D. N. 2020 Analisa InfrastrukturSaluranPembuangan Air LimbahEksisiting di Kelurahan 2 IlirKecamatan Ilir Timur II Kota Palembang. *J. Tek. Sipil* **9** (1), 16–24. https://doi.org/10.36546/tekniksipil.v9i1.265.

Rahman, M. Y., Nachabe, M. & Ergas, S. 2019 Efficacy of biochar amended bioretention for *E. coli* and nitrogen removal from urban runoff. In *Proceedings of the Water Environment Federation*. Water Environment Federation.

Rahmawan, A. J., Effendi, H. & Suprihatin, S. 2019 Potensi rumput vetiver (*Chrysopongon zizanoides* L.) dan kangkung (*Ipomoea aquatica* Forsk.) sebagai agen fitoremediasi limbah industri kayu. *J. Pengelolaan Sumberd. Alam dan Lingkung. (J. Nat. Resour. Environ. Manage.)* **9** (4), 904–919. https://doi.org/10.29244/jpsl.9.4.904-919.

Rezaei, A. R., Ismail, Z., Niksokhan, M. H., Dayarian, M. A., Ramli, A. H. & Shirazi, S. M. 2019 A quantity-quality model to assess the effects of source control stormwater management on hydrology and water quality at the catchment scale. *Water (Switzerland)* **11** (7). https://doi.org/10.3390/w11071415.

Rodríguez-Sinobas, L., Zubelzu, S., Perales-Momparler, S. & Canogar, S. 2018 Techniques and criteria for sustainable urban stormwater management. The case study of Valdebebas (Madrid, Spain). *J. Clean. Prod.* **172**, 402–416. https://doi.org/10.1016/j.jclepro.2017.10.070.

Rong, G., Hu, L., Wang, X., Jiang, H., Gan, D. & Li, S. 2021 Simulation and evaluation of low-impact development practices in university construction: a case study of Anhui University of Science and Technology. *J. Clean. Prod.* **294**, 126232. https://doi.org/10.1016/j.jclepro.2021.126232.

Rózsa, G., Csicsaiová, R., Šutús, M. & Škultétyová, I. 2020 Possibilities of usability of sediments flowing into a combined sewer network. *IOP Conf. Ser. Mater. Sci. Eng.* **867** (1). https://doi.org/10.1088/1757-899X/867/1/012036.

Sabory, N. R., Senjyu, T., Danish, M. S. S., Ahmadi, M., Zaheb, H. & Halim, M. 2021 A framework for integration of smart and sustainable energy systems in urban planning processes of low-income developing countries: Afghanistan case. *Sustainability* **13** (15), 60–80. https://doi.org/10.3390/su13158428.

Sanicola, O., Lucke, T. & Devine, J. 2018 Using permeable pavements to reduce the environmental impacts of urbanisation. *Int. J. GEOMATE* **14** (41), 159–166. https://doi.org/10.21660/2018.41.Key3.

Shafique, M. & Kim, R. 2018 Recent progress in low-impact development in South Korea: water-management policies, challenges and opportunities. *Water (Switzerland)* **10** (4). https://doi.org/10.3390/w10040435.

Shafique, M., Kim, R. & Kyung-Ho, K. 2018 Rainfall runoff mitigation by retrofitted permeable pavement in an urban area. *Sustainability* **10** (4), 1–10. https://doi.org/10.3390/su10041231.

Sharma, D., Rao, K. & Ramanathan, A. 2022 *A Systematic Review on the Impact of Urbanization and Industrialization on Indian Coastal Mangrove Ecosystem*. Coastal Research Library.

Shrestha, P., Hurley, S. E. & Wemple, B. C. 2018 Effects of different soil media, vegetation, and hydrologic treatments on nutrient and sediment removal in roadside bioretention systems. *Ecol. Eng.* **112**, 116–131. https://doi.org/10.1016/j.ecoleng.2017.12.004.

Si, S., Li, J., Jiang, Y., Wang, Y. & Liu, L. 2022 The response of runoff pollution control to initial runoff volume capture in sponge city construction using SWMM. *Appl. Sci.* **12** (11). https://doi.org/10.3390/app12115617.

Spraakman, S. & Drake, J. A. P. 2021 Hydrologic and soil properties of mature bioretention cells in Ontario, Canada. *Water Sci. Technol.* **84** (12), 3541–3560. https://doi.org/10.2166/wst.2021.464.

Sui, X. & van de Ven, F. H. M. 2023 The influence of low impact development (LID) on basin runoff in a half-urbanized catchment: a case study in San Antonio, Texas. *J. Hydrol.* **616**, 128793. https://doi.org/10.1016/j.jhydrol.2022.128793.

Sujatha, E. R., Sivaraman, S. & Subramani, A. K. 2020 Impact of hydration and gelling properties of guar gum on the mechanism of soil modification. *Arab. J. Geosci.* **13** (23). https://doi.org/10.1007/s12517-020-06258-x.

Surya, B., Salim, A., Hernita, H., Suriani, S., Abubakar, H. & Saleh, H. 2021 Handling slum settlement based on community participation and socio-cultural change: perspective of sustainable development of Makassar City, Indonesia. *Geogr. Pannonica* **25** (4), 300–316. https://doi.org/10.5937/gp25-33038.

Taghizadeh, S., Khani, S. & Rajaee, T. 2021 Hybrid SWMM and particle swarm optimization model for urban runoff water quality control by using green infrastructures (LID-BMPs). *Urban For. Urban Green.* **60**, 127032. https://doi.org/10.1016/j.ufug.2021.127032.

Taguchi, V. J., Weiss, P. T., Gulliver, J. S., Klein, M. R., Hozalski, R. M., Baker, L. A., Finlay, J. C., Keeler, B. L. & Nieber, J. L. 2020 It is not easy being green: recognizing unintended consequences of green stormwater infrastructure. *Water (Switzerland)* **12** (2). https://doi.org/10.3390/w12020522.

Takaijudin, H., Osman, M., Yusof, K. W., Ghani, A. A. & Weng, G. H. 2021 The effectiveness of cascaded bioretention system in treating urban stormwater runoff. *Lect. Notes Civ. Eng.* **132**, 39–46. https://doi.org/10.1007/978-981-33-6311-3_5.

Talebzadeh, F., Valeo, C., Gupta, R. & Peter Constabel, C. 2021 Exploring the potential in lid technologies for remediating heavy metals in carwash wastewater. *Sustainability* **13** (16). https://doi.org/10.3390/su13168727.

Tamaddun, K., Kalra, A. & Ahmad, S. 2018 Potential of rooftop rainwater harvesting to meet outdoor water demand in arid regions. *J. Arid Land* **10**, 68–83. https://doi.org/10.1007/s40333-017-0110-7.

Tang, W., Ma, H., Wang, X., Shao, Z., He, Q. & Chai, H. 2021 Study on the influence of sponge road bioretention facility on the stability of subgrade slope. *Water (Switzerland)* **13** (23), 1–17. https://doi.org/10.3390/w13233466.

Taufik, M., Khairina, E., Hidayat, R., Kalalinggi, R. & Fadhlurrohman, M. I. 2022 Study of government's strategy on clean water availability in Indonesia. *J. Kesehat. Lingkung. Indones.* **21** (1), 111–121. https://doi.org/10.14710/jkli.21.1.111-121.

Thiagarajan, M., Newman, G. & Van Zandt, S. 2018 The projected impact of a neighborhood-scaled green-infrastructure retrofit. *Sustainability* **10** (10). https://doi.org/10.3390/su10103665.

Tirpak, R. A., Afrooz, A. N., Winston, R. J., Valenca, R., Schiff, K. & Mohanty, S. K. 2021a Conventional and amended bioretention soil media for targeted pollutant treatment: a critical review to guide the state of the practice. *Water Res.* **189**. https://doi.org/10.1016/j.watres.2020.116648.

Tirpak, R. A., Winston, R. J., Simpson, I. M., Dorsey, J. D., Grimm, A. G., Pieschek, R. L., Petrovskis, E. A. & Carpenter, D. D. 2021b Hydrologic impacts of retrofitted low impact development in a commercial parking lot. *J. Hydrol.* **592**, 125773. https://doi.org/10.1016/j.jhydrol.2020.125773.

Torres, M. N., Fontecha, J. E., Zhu, Z., Walteros, J. L. & Rodríguez, J. P. 2020 A participatory approach based on stochastic optimization for the spatial allocation of sustainable urban drainage systems for rainwater harvesting. *Environ. Model. Softw.* **123**, 104532. https://doi.org/10.1016/j.envsoft.2019.104532.

Uddin Sikder, M. K. 2020 Ultraviolet disinfection of potable water in rainwater harvesting systems. *Int. J. Eng. Appl. Sci. Technol.* **04** (11), 557–563. https://doi.org/10.33564/ijeast.2020.v04i11.098.

Van Steenbergen, F., Tuinhof, A., 2021 In: *Water-wise Cities and Sustainable Water Systems. Angew. Chemie Int. Ed. 6(11), 951–952.* (Wang, X. C. & Fu, G. eds.). IWA Publishing, London.

Vujovic, S., Haddad, B., Karaky, H., Sebaibi, N. & Boutouil, M. 2021 Urban heat island: causes, consequences, and mitigation measures with emphasis on reflective and permeable pavements. *CivilEng* **2** (2), 459–484. https://doi.org/10.3390/civileng2020026.

Wang, Z., Zhou, S., Wang, M. & Zhang, D. 2020 Cost-benefit analysis of low-impact development at hectare scale for urban stormwater source control in response to anticipated climatic change. *J. Environ. Manage.* **264**, 110483. https://doi.org/10.1016/j.jenvman.2020.110483.

Wang, J., Meng, Q., Zou, Y., Qi, Q., Tan, K., Santamouris, M. & He, B. J. 2022 Performance synergism of pervious pavement on stormwater management and urban heat island mitigation: a review of its benefits, key parameters, and co-benefits approach. *Water Res.* **221**. https://doi.org/10.1016/j.watres.2022.118755.

Wardoyo, S., Destiasari, F., Wayhudin, W., Hasibuan, G. & Sollu, W. P. 2019 *Atlas Sebaran Tanah Lunak Indonesia*. Badan Geologi Kementerian Eneri dan Sumber Daya Mineral, Bandung.

Wendling, L. A. & Holt, E. E. 2020 *Integrating Engineered and Nature-Based Solutions for Urban Stormwater Management*.

Widjojo, R. & Agus, I. 2018 Rain barrel project: rainwater harvesting for sustainable water supply in urban households. In: *3rd International Conference of Integrated Intellectual Community*. ICONIC, Hanover.

Winston, R. J., Arend, K., Dorsey, J. D. & Hunt, W. F. 2020 Water quality performance of a permeable pavement and stormwater harvesting treatment train stormwater control measure. *Blue-Green Syst.* **2** (1), 91–111. https://doi.org/10.2166/bgs.2020.914.

Wu, J. 2021 Preliminary study on the landscape design of sponge campus based on LID concept – a case study of landscape design in Wuhan University of Technology. In *IOP Conference Series: Earth and Environmental Science*.

Xiang, C., Liu, J., Shao, W., Mei, C. & Zhou, J. 2019 Sponge city construction in China: policy and implementation experiences. *Water Policy* **21** (1), 19–37. https://doi.org/10.2166/wp.2018.021.

Xie, J., Chen, H., Liao, Z., Gu, X., Zhu, D. & Zhang, J. 2017 An integrated assessment of urban flooding mitigation strategies for robust decision making. *Environ. Model. Softw.* **95**, 143–155. https://doi.org/10.1016/j.envsoft.2017.06.027.

Xiong, J., Li, G., Zhu, J., Li, J., Yang, Y., An, S. & Liu, C. 2021 Removal characteristics of heavy metal ions in rainwater runoff by bioretention cell modified with biochar. *Environ. Technol. (United Kingdom)*, 1–13. https://doi.org/10.1080/09593330.2021.1954697.

Xu, L., Yang, S., Zhang, Y., Jin, Z., Huang, X., Bei, K., Zhao, M., Kong, H. & Zheng, X. 2020 A hydroponic green roof system for rainwater collection and greywater treatment. *J. Clean. Prod.* **261**, 121132. https://doi.org/10.1016/j.jclepro.2020.121132.

Xu, D., Cui, Y. & She, N. 2022 Is green infrastructure viable for mitigating pluvial floods? A retrospective study of a community renovation applying LID principal and practice in Zhenjiang City of China. *J. Environ. Sci. Eng. B* **11** (3), 70–82. https://doi.org/10.17265/2162-5263/2022.03.002.

Yang, T. & Dong, Z. 2021 The effect of sponge city construction on non-point source load reduction: a case study in the Three Gorges Reservoir Area, China. *Ecohydrol. Hydrobiol.* **21** (2), 223–232. https://doi.org/10.1016/j.ecohyd.2020.12.002.

Yang, Q., Beecham, S., Liu, J. & Pezzaniti, D. 2019 The influence of rainfall intensity and duration on sediment pathways and subsequent clogging in permeable pavements. *J. Environ. Manage.* **246**, 730–736. https://doi.org/10.1016/j.jenvman.2019.05.151.

Yang, W., Brüggemann, K., Seguya, K. D., Ahmed, E., Kaeseberg, T., Dai, H., Hua, P., Zhang, J. & Krebs, P. 2020 Measuring performance of low impact development practices for the surface runoff management. *Environ. Sci. Ecotechnol.* **1**, 100010. https://doi.org/10.1016/j.ese.2020.100010.

Ye, J., Chen, Y., Yang, H., Chen, Q., Huang, Y., Zhao, J., Hospital, X., Hospital, X., Women, H., Hospital, X., Hospital, X., Hospital, X., Maternal, C., Hospital, I. H., Hospital, S. O. & Hospital, X. 2020 Agent-based simulation of citizen participation in nature-based projects. *The Lancent Pschch*, 1–35.

Yin, D., Evans, B., Wang, Q., Chen, Z., Jia, H., Chen, A. S., Fu, G., Ahmad, S. & Leng, L. 2020 Integrated 1D and 2D model for better assessing runoff quantity control of low impact development facilities on community scale. *Sci. Total Environ.* **720**, 137630. https://doi.org/10.1016/j.scitotenv.2020.137630.

Yustiani, Y. M., Wahyuni, S. & Alfian, M. R. 2018 Investigation on the deoxygenation rate of water of Cimanuk river, Indramayu, Indonesia. *Rasayan J. Chem.* **11** (2), 475–481. https://doi.org/10.7324/RJC.2018.1121892.

Zabidi, H. A., Goh, H. W., Chang, C. K., Chan, N. W. & Zakaria, N. A. 2020 A review of roof and pond rainwater harvesting systems for water security: the design, performance and way forward. *Water (Switzerland)* **12** (11), 1–22. https://doi.org/10.3390/w12113163.

Zhai, J., Ren, J., Xi, M., Tang, X. & Zhang, Y. 2021 Multiscale watershed landscape infrastructure: integrated system design for sponge city development. *Urban For. Urban Green.* **60**, 127060. https://doi.org/10.1016/j.ufug.2021.127060.

Zhu, H., Yu, M., Zhu, J., Lu, H. & Cao, R. 2019a Simulation study on effect of permeable pavement on reducing flood risk of urban runoff. *Int. J. Transp. Sci. Technol.* **8** (4), 373–382. https://doi.org/10.1016/j.ijtst.2018.12.001.

Zhu, Z., Chen, Z., Chen, X. & Yu, G. 2019b An assessment of the hydrologic effectiveness of low impact development (LID) practices for managing runoff with different objectives. *J. Environ. Manage.* **231**, 504–514. https://doi.org/10.1016/j.jenvman.2018.10.046.

Zhu, Y., Li, H., Yang, B., Zhang, X., Mahmud, S., Zhang, X., Yu, B. & Zhu, Y. 2021 Permeable pavement design framework for urban stormwater management considering multiple criteria and uncertainty. *J. Clean. Prod.* **293**, 126114. https://doi.org/10.1016/j.jclepro.2021.126114.

First received 14 February 2023; accepted in revised form 16 March 2023. Available online 28 March 2023