

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

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ABSTRACT

Low impact development (LID) is a sustainable land use and planning strategy that aims to minimize the environmental impacts of development. A community can enhance their water resources and create sustainable and resilient neighbourhoods. 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.
- With proper planning and site-specific strategies that address these challenges, LID can be implemented effectively in Indonesia.

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).

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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 Steenberghe & 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 <i>et al.</i> (2021)
RB	18–40	–	–	–	–	–	–	–	–	RB ability depends on the installation site and RB storage volume	Oberascher <i>et al.</i> (2019)
RB	–	81	97	–	–	–	–	–	–	Using the combination of RB and green roof	Xu <i>et al.</i> (2020)
RB	–	–	–	40	77	75	–	–	–	Collecting and storing rainwater results in the amount of runoff that pollutes the stormwater system being reduced	Imteaz <i>et al.</i> (2022)
BR	48–96	–	–	–	–	–	–	–	–	By detaining and filtering runoff through vegetation, soil, and other materials	Shrestha <i>et al.</i> (2018)
BR	–	–	–	80	–	80.4	–	–	–	Using recyclable materials (shredded printed paper, coconut husk, cockle shell, tire crumb, and shredded newspaper) as potential additives	Goh <i>et al.</i> (2017)
BR	–	80	72	–	–	–	–	–	–	Using a cascaded bioretention system	Takaijudin <i>et al.</i> (2021)
BR	–	–	–	–	97	93	–	–	–	Natural chemical and biological processes	Goh <i>et al.</i> (2019)
BR	–	–	–	–	–	–	66	99	73	By chemical processes including adsorption, absorption, and remediation	Caldelas <i>et al.</i> (2021)
PP	30–65	–	–	–	–	–	–	–	–	Penetrate water through the surface and into the soil	Shafique <i>et al.</i> (2018)
PP	–	100	–	–	–	–	–	–	–	By physical filtering process	Kamali <i>et al.</i> (2017)
PP	–	–	–	–	–	–	79	92	88	Using interlocking concrete pavement (PICP) that built over a low-conductivity clay soil	Braswell <i>et al.</i> (2018)
PP	27	–	–	99.5	59	78	–	–	–	Using the cistern as a final polishing	Winston <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (2018) and Fowdar <i>et al.</i> (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 <i>et al.</i> (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 <i>et al.</i> (2021)
Cost	Maybe less appealing for some property owners or municipalities due to higher installation costs	Yang <i>et al.</i> (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 <i>et al.</i> (2021), Sanicola <i>et al.</i> (2018), Wang <i>et al.</i> (2022), and Yang <i>et al.</i> (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 <i>et al.</i> (2019) and Talebzadeh <i>et al.</i> (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 m³ 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; Jokowiarno & 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 (Sprakman & 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)			Source
RB	BR	PP	RB	BR	PP	
6.71–8.59	–	75–150	0.077	–	1.01	Xie <i>et al.</i> (2017)
–	320.97	52.97	–	1.28	0.00	Johnson & Geisendorf (2019)
–	–	50.71–77.29	–	–	1.01–1.57	Yang <i>et al.</i> (2020)
–	–	28–150	–	–	0.90	Mei <i>et al.</i> (2018)
–	76.5–224	58–72	–	518–544*	13–109*	Chui <i>et al.</i> (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 inconsistencies 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 (Nawiswary & Tangahu 2017). Research on phytoremediation has been conducted in Indonesia, and several plant species, including *Chrysopogon zizanioides* L. (Rahmawan *et al.* 2019), *Acanthus ilicifolius* (Intan Fatiha *et al.* 2020), *Pandanus amaryllifolius* Roxb. (Ambardini *et al.* 2020), *Actinoscirpus grossus*, and *Thypha 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 (Sprakman & Drake 2021). Thus, basically, sandy soil is more suitable for PP practices than BR, 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). Like BR and PP, RB has had some issue with soil characteristics when it comes to water quality and quantity. For water reuse purposes, it is better to ensure that the stored water in RB is from roof tops only, not from the surrounding land nor sewerage due to the presence of pollutants (Hamilton *et al.* 2018). To anticipate the occurrence of contaminated stored water, the use of a filter device is necessary (Chu 2021). In addition, low permeability soil with shallow groundwater table characteristics and bad drainage system can affect the performance of the RB (Oberascher *et al.* 2019; Palanisamy *et al.* 2020). Based on (Araujo *et al.* 2021), during heavy rainfalls, the store water in small tanks can overflow onto surrounding areas, creating flooding in areas with low permeability soil. Therefore, it's better to provide proper designs that are integrated with drainage network systems, especially in areas with a shallow groundwater table. Leak tanks for instance, can detain stormwater at the source and discharge it slowly for a longer duration, which is a believable option to mitigate peak urban runoff flow and automatically reset tanks to an empty state to avoid overflow, based on Qin (2020). 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.

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.

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 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 the author on request.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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