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Review Article

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Sustainable Drainage Systems (SuDS) in Urban Drainage Planning: A Mini Review

Ahmad Maarif [a],*, Alpian Nur [a] and Tukimun [a]

[a] Department of Civil Engineering, Faculty of Engineering, 17 Agustus 1945 University, Kota Samarinda, 75243 Kalimantan Timur, Indonesia.

* Correspondence: ahmadmaarif16.am@gmail.com

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Abstract

Rapid urbanization and climate change have significantly increased the frequency and intensity of urban flooding, highlighting the limitations of conventional drainage systems that rely on rapid stormwater conveyance. These systems often fail to address broader hydrological and environmental impacts, necessitating more sustainable and integrated approaches. This study aims to review the role of Sustainable Drainage Systems (SuDS) in urban drainage planning and to synthesize current knowledge on their effectiveness, implementation, and emerging trends. A mini-review methodology was employed, involving a structured analysis of peer-reviewed literature published between 2014 and 2024. The findings indicate that SuDS, including green infrastructure and nature-based solutions, effectively reduce runoff, improve water quality, and enhance urban resilience by restoring natural hydrological processes. Additionally, the integration of hybrid green–grey infrastructure systems has gained increasing attention as a practical and adaptive strategy for urban stormwater management. However, the implementation of SuDS remains constrained by institutional, technical, and planning-related barriers. This review concludes that SuDS plays a critical role in advancing sustainable urban water management, and its successful integration requires supportive policies, interdisciplinary collaboration, and comprehensive urban planning frameworks.

1. Introduction

Rapid urbanization has significantly transformed natural hydrological processes in urban environments. The expansion of impervious surfaces, such as roads, rooftops, and parking areas, reduces the natural infiltration capacity and disrupts the hydrological cycle. As a result, urban areas experience increased surface runoff volumes, higher peak discharge rates, and a greater frequency of flooding events. These impacts are further intensified by climate change, which has contributed to more frequent and intense rainfall events in many regions of the world (Fletcher, Andrieu, & Hamel, 2013; Zhou, 2014). Consequently, urban flooding has emerged as one of the most pressing environmental challenges facing modern cities.

Traditional urban drainage systems were historically designed primarily to rapidly convey stormwater away from urban areas through underground pipe networks and channelized drainage systems. While this approach has been effective in reducing localized water accumulation, it often neglects the broader environmental and hydrological consequences. Conventional systems typically accelerate the transfer of stormwater into downstream water bodies, increasing erosion, degrading aquatic ecosystems, and reducing water quality (Eckart, McPhee, & Bolisetti, 2017). Furthermore, these systems are generally designed based on historical rainfall patterns and are therefore increasingly vulnerable to extreme weather events associated with climate change (Fletcher et al., 2013). As urban populations continue to grow and climate variability increases, conventional drainage infrastructure alone is insufficient to sustainably manage urban stormwater.

In recent decades, there has been growing recognition that urban stormwater should not be treated merely as a waste product but rather as a valuable resource within the urban water cycle. This paradigm shift has led to the development of alternative stormwater management approaches that aim to replicate natural hydrological processes within urban environments. One of the most prominent approaches is Sustainable Drainage Systems (SuDS), which focuses on source control and decentralized stormwater management through infiltration, detention, retention, and evapotranspiration (Fletcher et al., 2015; Zhou, 2014). By slowing, storing, and filtering stormwater close to its source, SuDS aim to restore pre-development hydrological conditions while simultaneously improving water quality and reducing flood risk.

SuDS approaches are closely related to several internationally recognized concepts in sustainable urban water management, including Low Impact Development (LID), Best Management Practices (BMPs), and Water Sensitive Urban Design (WSUD). Although these terms originate from different regional contexts, they share common principles emphasizing decentralized stormwater management, green infrastructure, and the restoration of natural hydrological processes (Fletcher et al., 2015). Techniques commonly associated with SuDS include permeable pavements, green roofs, rain gardens, bioretention systems, infiltration trenches, and constructed wetlands, all of which improve stormwater management while enhancing urban environmental quality.

Beyond hydrological benefits, SuDS can deliver a wide range of environmental, social, and economic co-benefits. These systems can enhance urban biodiversity, improve microclimate regulation, increase the availability of green space, and support recreational opportunities in cities (Oral et al., 2020). In addition, integrating green and grey infrastructure solutions has been shown to improve urban flood resilience while simultaneously generating social and environmental co-benefits (Alves et al., 2018). Such multifunctional benefits align with broader urban sustainability and resilience objectives, which aim to improve cities' capacity to adapt to environmental uncertainties and climate-related risks (Meerow, Newell, & Stults, 2016).

Despite growing recognition of the benefits of SuDS, their implementation in many urban areas remains limited. Several studies have identified significant barriers to the widespread adoption of green infrastructure and sustainable stormwater management approaches. These barriers include institutional constraints, fragmented governance structures, limited technical knowledge, financial limitations, and insufficient public awareness (Dhakal & Chevalier, 2017). In many cities, stormwater management policies and regulations continue to prioritize traditional grey infrastructure, hindering the integration of SuDS into urban planning and infrastructure development.

Recent research also indicates a growing shift in urban stormwater management toward hybrid approaches that combine conventional grey infrastructure with green infrastructure solutions. Bibliometric analyses show that research activity in this field has increased significantly in recent years, with particular emphasis on optimizing stormwater management through integrated and multi-objective frameworks (Wang et al., 2023). These hybrid systems are increasingly recognized as an effective strategy for improving urban resilience while maintaining the reliability of existing drainage infrastructure.

Although the literature on sustainable stormwater management has expanded considerably over the past two decades, there remains a need to synthesize and critically evaluate current knowledge on the role of SuDS in urban drainage planning. Many studies focus on specific technologies or case studies, but fewer studies provide a comprehensive overview of the broader planning implications of SuDS implementation in urban environments. Moreover, the integration of SuDS within urban planning frameworks remains uneven across different regions, highlighting the need for further examination of the current state of knowledge and emerging research trends.

Therefore, the objective of this study is to conduct a mini-review of the existing literature on Sustainable Drainage Systems (SuDS) in urban drainage planning. Specifically, this study aims to (1) examine the key concepts and principles underlying SuDS, (2) identify the main benefits and challenges associated with their implementation, and (3) highlight current research trends and future directions for integrating SuDS into sustainable and resilient urban water management systems.

2. Literature Review

2.1 Research Design

This study adopts a mini-review approach to synthesize recent scholarly literature on the role of Sustainable Drainage Systems (SuDS) in urban drainage planning. A structured literature review method was applied to identify and summarize key developments, implementation strategies, and performance outcomes of SuDS in urban stormwater management. The approach provides a concise yet comprehensive overview of current research trends and planning practices for SuDS.

2.2 Literature Search Strategy

Relevant literature was identified through searches in major academic databases, including Scopus, Web of

Science, and Google Scholar. The search focused on peer-reviewed journal articles published in English. Keywords were combined using Boolean operators to capture relevant studies, including: *"sustainable drainage systems", "SuDS", "urban drainage planning", "stormwater management", "green infrastructure",* and *"urban flood mitigation".*

The search period primarily covered recent publications from 2014 to 2024, ensuring the inclusion of contemporary developments in SuDS research and urban drainage planning.

2.3 Selection Criteria

To ensure relevance to the research topic, the reviewed studies were selected using the following criteria.

Included studies:

- Addressed Sustainable Drainage Systems (SuDS) or related approaches such as Low Impact Development (LID), Water Sensitive Urban Design (WSUD), or green infrastructure.
- Focused on urban drainage planning, stormwater management, or urban flood mitigation.
- Discussed planning strategies, design principles, performance evaluation, or policy aspects of SuDS.
- Published as peer-reviewed journal articles.

Excluded studies:

- Studies focusing exclusively on rural drainage systems.
- Research dealing solely with wastewater treatment or sewer systems without stormwater relevance.
- Non-peer-reviewed materials such as editorial notes or short conference abstracts.

2.4 Study Selection Process

The literature screening process involved reviewing article titles, abstracts, and full texts to identify studies relevant to SuDS-based urban drainage planning. Duplicate and unrelated records were removed during the initial screening stage. The remaining studies were assessed for relevance and methodological clarity before inclusion in the final review.

2.5 Data Extraction and Analysis

Key information from the selected studies was extracted and summarized to support comparative analysis. The extracted data included:

- authors and year of publication,
- geographical context of the study,
- types of SuDS or green infrastructure applied,
- planning or design approaches,
- reported hydrological benefits (e.g., runoff or flood reduction), and
- environmental or social co-benefits.

The selected studies were then categorized based on SuDS typology, implementation scale, and methodological approach to identify common themes and research patterns.

2.6 Data Synthesis

A descriptive synthesis was conducted to summarize the main findings of the reviewed literature. The analysis focused on identifying common planning strategies, implementation approaches, and performance outcomes associated with SuDS in urban drainage systems. Comparative insights were also drawn to highlight differences in SuDS applications across various geographical and climatic contexts.

2.7 Limitations

This mini-review is limited to English-language publications and selected academic databases, which may exclude some regional studies and grey literature. However, the structured review process provides a focused overview of current research on the application of SuDS in urban drainage planning.

3. Results

3.1. Overview of Reviewed Studies

The literature search identified several studies on sustainable urban drainage and stormwater management strategies. After screening titles, abstracts, and full texts against predefined inclusion criteria, 10 key studies were selected for the final review. These studies represent a diverse range of methodological approaches, including literature reviews, bibliometric analyses, experimental studies, policy analyses, and decision-support frameworks.

Most of the reviewed studies focus on green infrastructure, nature-based solutions, and integrated drainage approaches, reflecting the growing shift from traditional grey infrastructure toward more sustainable and resilient urban water management systems. Table 1 summarizes the key characteristics of the selected studies, including the research method, main findings, SuDS-related technologies, and study location.

Table 1. Summary of Reviewed Studies on SuDS and Urban Drainage Planning

No	Author(s) & Year	Method	Key Findings	SuDS Type(s)	Study Location
1	Alves et al. (2018)	Multi-criteria analysis	Integration of green and grey infrastructure improves flood risk reduction and generates environmental co-benefits	Hybrid green–grey infrastructure	Europe
2	Dhakal & Chevalier (2017)	Policy analysis	Identified institutional and governance barriers to green infrastructure implementation	Green infrastructure	USA
3	Eckart et al. (2017)	Literature review	LID techniques can restore natural hydrology and improve stormwater management	LID systems	Global
4	Fletcher et al. (2013)	State-of-the-art review	Advances in urban hydrology modeling improve stormwater prediction and management	SuDS concepts	Global
5	Fletcher et al. (2015)	Conceptual review	Clarifies terminology differences between SuDS, LID, BMPs, and WSUD	Multiple SuDS concepts	Global
6	Meerow et al. (2016)	Literature review	Urban resilience frameworks support climate-adaptive urban infrastructure	Resilient urban infrastructure	Global
7	Musa & Idrus (2020)	Experimental study	Anaerobic treatment technologies improve wastewater management and resource recovery	Sustainable water treatment	Malaysia
8	Zhou (2014)	Literature review	SuDS improve water quality and flood mitigation under climate change and urbanization	SuDS technologies	Global
9	Oral et al. (2020)	Literature and case studies	Nature-based solutions enhance biodiversity and water management in circular cities	Nature-based solutions	Europe
10	Wang et al. (2023)	Bibliometric analysis	Research trends show growing emphasis on hybrid green–grey infrastructure systems	LID and green infrastructure	Global

3.2. Distribution of Research Methods

The literature review demonstrates a range of research approaches used to study sustainable drainage systems in urban contexts. Among the selected studies, literature reviews represent the largest proportion, followed by conceptual analyses, experimental studies, and bibliometric research. This methodological diversity highlights the interdisciplinary nature of SuDS research, which combines hydrology, environmental engineering, urban planning, and sustainability science.

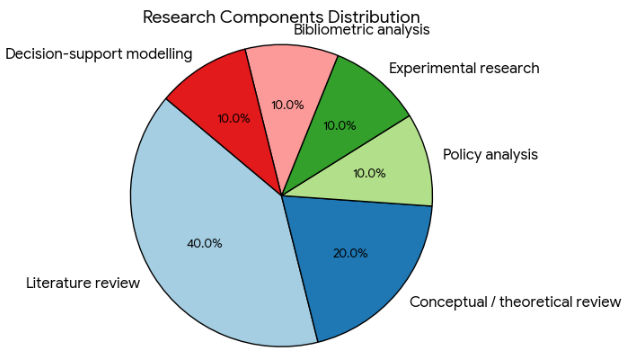

Figure 1. Distribution of Research Methods in Reviewed Studies

Figure 1 shows that the dominance of review-based studies suggests the field of sustainable drainage systems is still evolving, with ongoing efforts to consolidate knowledge and identify best practices for implementation.

3.3 Types of Sustainable Drainage Systems Identified

The literature reveals a wide range of SuDS technologies designed to manage stormwater through natural hydrological processes. These systems aim to reduce surface runoff, improve water quality, and enhance urban environmental conditions. Common SuDS components identified in the reviewed studies include:

- Bioretention systems (rain gardens)
- Permeable pavements
- Green roofs
- Constructed wetlands
- Infiltration trenches
- Detention and retention ponds

These technologies operate through mechanisms such as infiltration, detention, filtration, and evapotranspiration, helping to replicate natural hydrological processes that are often disrupted by urban development (see Figure 2).

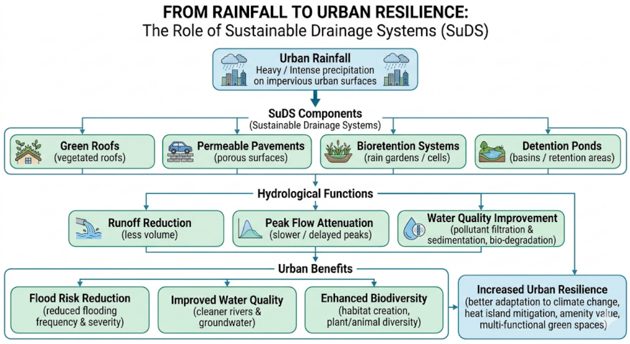

Figure 2. Conceptual Framework of SuDS in Urban Drainage Planning

3.4 Hydrological and Environmental Performance of SuDS

The reviewed studies consistently highlight the effectiveness of SuDS in improving urban stormwater management. Hydrological benefits reported in the literature include:

- Reduction of peak runoff discharge
- Decrease in stormwater volume
- Improvement of groundwater recharge
- Enhanced pollutant removal efficiency

Several studies emphasize that decentralized stormwater control systems can significantly reduce the burden on conventional drainage infrastructure (Eckart et al., 2017; Zhou, 2014). Furthermore, integrating green and grey infrastructure solutions can provide improved flood protection while also delivering environmental and social co-benefits (Alves et al., 2018). In addition to hydrological benefits, SuDS also contribute to broader urban sustainability goals. Nature-based solutions associated with SuDS can enhance biodiversity, improve urban microclimates, and increase the availability of green spaces within cities (Oral et al., 2020).

3.5 Emerging Trends in Urban Drainage Planning

Recent research indicates a shift toward integrated urban water management approaches that combine multiple stormwater management strategies. Bibliometric analysis shows a significant increase in research activity related to green infrastructure and sustainable drainage systems since 2014 (Wang et al., 2023). The literature suggests several emerging trends:

- Increasing adoption of nature-based solutions for stormwater management.
- Growing integration of hybrid green–grey infrastructure systems.
- Expansion of multi-objective planning frameworks addressing hydrological, environmental, and social outcomes.
- Greater emphasis on urban resilience and climate adaptation.

These developments reflect the recognition that sustainable urban drainage planning requires not only technical solutions but also integrated policy frameworks and cross-disciplinary collaboration.

4. Conclusions

4.1 Transition from Conventional Drainage to SuDS-Based Approaches

The findings of this review highlight a clear shift in urban drainage planning from conventional grey infrastructure toward more sustainable, integrated approaches. Traditional drainage systems, which focus on rapid stormwater conveyance, are increasingly recognized as insufficient in addressing the complex challenges posed by urbanization and climate change. As noted by Fletcher et al. (2013), conventional systems often fail to account for the broader hydrological cycle and their impacts on receiving water bodies, leading to ecological degradation and reduced water quality.

In contrast, Sustainable Drainage Systems (SuDS) aim to replicate natural hydrological processes by promoting infiltration, retention, and evapotranspiration. This shift reflects a fundamental change in how stormwater is perceived—from a waste product to a valuable resource within the urban water cycle. Zhou (2014) emphasizes that SuDS provide a more adaptive and environmentally responsive approach to managing urban runoff, particularly under conditions of increasing rainfall variability.

Furthermore, the integration of green and grey infrastructure has emerged as a key strategy in enhancing urban flood resilience. Alves et al. (2018) demonstrate that hybrid systems can effectively reduce flood risk while simultaneously generating environmental and social co-benefits. This indicates that the future of urban drainage planning lies not in replacing conventional systems entirely, but in complementing them with sustainable solutions.

4.2 Effectiveness of SuDS in Urban Stormwater Management

The reviewed studies consistently confirm the effectiveness of SuDS in improving hydrological performance. Techniques such as bioretention systems, permeable pavements, and green roofs have been shown to significantly reduce runoff volume and peak discharge while improving water quality (Eckart et al., 2017). These findings support the argument that decentralized stormwater management systems can alleviate pressure on centralized drainage infrastructure.

In addition to hydrological benefits, SuDS contribute to broader environmental outcomes. Nature-based solutions, as highlighted by Oral et al. (2020), enhance biodiversity, regulate urban microclimates, and improve ecosystem services. Such multifunctional benefits are particularly important in densely populated urban areas where space is limited, and infrastructure must serve multiple purposes.

Moreover, SuDS play a crucial role in advancing urban resilience. Meerow et al. (2016) emphasize that resilience in urban systems requires the capacity to absorb, adapt, and transform in response to disturbances. By incorporating flexible and adaptive design principles, SuDS contribute to building resilient urban environments capable of responding to climate-related risks.

4.3 Barriers to SuDS Implementation

Despite the demonstrated benefits of SuDS, their implementation remains limited in many urban contexts. One of the most significant challenges identified in the literature is the presence of institutional and governance barriers. Dhakal and Chevalier (2017) identify a wide range of obstacles, including fragmented regulatory frameworks, a lack of coordination among stakeholders, and limited awareness of green infrastructure benefits.

Technical and economic constraints also limit the adoption of SuDS. In many cases, decision-makers prioritize conventional infrastructure due to its perceived reliability and familiarity. Additionally, uncertainties regarding the long-term performance and maintenance requirements of SuDS can hinder their widespread implementation (Eckart et al., 2017).

Another important challenge relates to the integration of SuDS into urban planning frameworks. While SuDS are often promoted as sustainable solutions, their implementation requires alignment with land-use planning, policy instruments, and urban design strategies. The lack of integrated planning approaches can result in fragmented or isolated implementation of SuDS, reducing their overall effectiveness.

4.4 Emerging Trends and Research Directions

The analysis of recent literature reveals several important trends shaping the future of urban drainage planning. One notable trend is the increasing adoption of hybrid green–grey infrastructure systems, which combine the strengths of traditional and sustainable approaches. Wang et al. (2023) highlight that recent research has shifted toward multi-objective optimization frameworks that consider not only hydrological performance but also environmental and social outcomes.

Another emerging trend is the growing emphasis on nature-based solutions (NBS) within circular urban water systems. Oral et al. (2020) suggest that NBS can play a critical role in creating regenerative urban environments by integrating water management with ecological and social functions. This aligns with the broader concept of sustainable cities, where infrastructure is designed to support both human and environmental well-being.

In addition, there is increasing recognition of the importance of interdisciplinary approaches in urban drainage planning. Fletcher et al. (2015) argue that the diversity of terminology (e.g., SuDS, LID, WSUD, BMPs) reflects the need for context-specific solutions tailored to local conditions. However, this diversity also underscores the importance of clear communication and integration of knowledge across disciplines.

5. Conclusions

This mini-review highlights the growing importance of Sustainable Drainage Systems (SuDS) in advancing urban drainage planning toward more sustainable, resilient approaches. The findings demonstrate that SuDS provide significant advantages over conventional drainage systems by promoting natural hydrological processes such as infiltration, retention, and evapotranspiration. These mechanisms help reduce surface runoff, mitigate flood risks, and improve urban water quality.

In addition to hydrological benefits, SuDS offer a wide range of environmental and social co-benefits, including enhanced biodiversity, improved urban microclimates, and increased availability of green space. The integration of green and grey infrastructure has emerged as a particularly effective strategy, combining the reliability of traditional systems with the sustainability of nature-based solutions. Furthermore, recent research trends indicate a shift toward hybrid and multi-objective approaches, emphasizing the role of SuDS in supporting urban resilience and climate adaptation.

However, despite their proven effectiveness, the widespread implementation of SuDS remains constrained by several challenges. Institutional barriers, fragmented governance structures, limited technical capacity, and insufficient integration into urban planning frameworks continue to hinder adoption. Addressing these challenges requires stronger policy support, interdisciplinary collaboration, and increased awareness among stakeholders.

Thus, this review underscores that SuDS represent a critical component of sustainable urban water management. Future efforts should focus on integrating SuDS into comprehensive urban planning strategies, supported by long-term performance evaluation and adaptive governance frameworks. By doing so, cities can enhance their capacity to respond to climate change, reduce flood risks, and promote more livable and environmentally sustainable urban environments.

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A.N.: Alpian Nur
T.K.: Tukimun

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