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Strategies for Enhancing Urban Drainage System Performance in Reducing Inundation Risk: A Literature Review with Implications for Bone Regency

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ABSTRACT

Rapid urban development increases surface runoff and reduces soil infiltration capacity, thereby amplifying the risk of inundation due to the imbalance between runoff discharge and drainage system capacity. This issue is not confined to major metropolitan areas but has also begun to emerge in developing regions such as Bone Regency. This study aims to identify strategies for enhancing the performance of urban drainage systems based on systems and resilience-oriented approaches, and to formulate their implications for reducing inundation risk in Bone Regency. The research adopts a qualitative approach using a narrative literature review method, encompassing national and international publications from 2000 to 2025. The analysis was conducted through thematic synthesis of key concepts, including system performance indicators, the integration of gray and green infrastructure, and urban drainage resilience frameworks. The findings indicate that improving drainage performance must be grounded in comprehensive evaluation of hydrological and hydraulic indicators, runoff control at the source through nature-based solutions, and the application of system flexibility and adaptive capacity principles. Such an integrated approach is highly relevant for supporting more responsive and sustainable drainage planning in Bone Regency. This study provides a conceptual contribution by developing a systemic and long-term performance enhancement framework for urban drainage systems.

INTRODUCTION

Rapid urban development has significantly altered the hydrological characteristics of urban areas. The conversion of open land into built-up areas increases the runoff coefficient, accelerates surface flow, and reduces soil infiltration capacity (Chow et al., 1988; Akan & Houghtalen, 2003). These changes create an imbalance between runoff discharge and drainage system capacity, thereby increasing the frequency and duration of urban inundation (Tucci, 2007; Suripin, 2016). In the Indonesian context, inundation issues are no longer confined to metropolitan cities but have also emerged in developing cities and regencies due to settlement expansion that is not fully integrated with drainage system planning (Ministry of Public

Works and Housing, 2022; Bappenas, 2021).

Conceptually, drainage system performance is not solely measured by the capacity of channels to convey design discharge, but also by the system's ability to attenuate peak flows, minimize inundated areas, and reduce drain-down time (Ashley et al., 2007; Butler & Davies, 2011). International literature indicates that conventional approaches focused primarily on channel enlargement are often insufficient if not accompanied by runoff control at the catchment scale (Fletcher et al., 2015; Ahiablame et al., 2012). Consequently, the paradigm of urban drainage management has shifted from purely structural measures toward system-based and resilience-oriented approaches (urban drainage resilience), emphasizing flexibility, redundancy, and adaptive capacity (Meerow et al., 2016; Mugume & Butler, 2017).

In Indonesia, various studies reveal that urban inundation is frequently caused by a combination of inadequate hydraulic capacity, sedimentation, uncontrolled land-use change, and weak integration between spatial planning and infrastructure development (Suripin, 2016; Yuliani et al., 2019; Jurnal Rekayasa Sipil, 2021). Technical evaluations of channel capacity through hydrological and hydraulic analyses often demonstrate that actual discharge exceeds design discharge due to increased rainfall intensity and expansion of impervious surfaces (BMKG, 2023; Kodoatie & Sjarief, 2010). However, most studies remain focused on partial evaluations of channel capacity without examining comprehensive and integrated strategies for improving overall system performance (Salim et al., 2020; Prasetyo & Nugroho, 2022). This limitation indicates that infrastructure-related problems, including urban drainage systems, should be understood as systemic rather than purely technical issues. As highlighted by Amir et al. (2026), Project delay is not merely a scheduling issue but a systemic problem within construction project governance."

In the context of Bone Regency, the growth of built-up areas and expanding economic activities have the potential to intensify pressure on existing drainage systems. The regional characteristics, including a combination of lowland and coastal areas, increase the likelihood of runoff accumulation when conveyance systems are suboptimal (Kodoatie & Sjarief, 2010; Suripin, 2016). Furthermore, land-use change and increasing building density may significantly raise runoff coefficients, accelerating the occurrence of inundation if system capacity is not adaptively enhanced (Chow et al., 1988; Tucci, 2007).

A gap in the literature is evident in the absence of a comprehensive synthesis on system- and resilience-based strategies for enhancing drainage system performance, particularly when linked to implications for developing regions such as Bone Regency (Meerow et al., 2016; Mugume & Butler, 2017). This study differs from previous technical investigations by developing an integrated conceptual framework for drainage performance enhancement based on national and international literature and translating it into the context of a developing regency.

Accordingly, this study aims to identify system- and resilience-based approaches to improving drainage system performance, analyze effective strategies for reducing inundation risk, and formulate conceptual implications for the development of drainage systems in Bone Regency.

METHOD

This study adopts a qualitative approach using a narrative literature review method to develop a conceptual synthesis of strategies for enhancing urban drainage system performance based on a systems and resilience-oriented approach. This method was selected because the objective of the research is not to evaluate drainage performance through field measurements, but rather to integrate theoretical and empirical findings from various studies in order to construct a conceptual framework applicable to developing regions such as Bone Regency. A narrative review enables an in-depth exploration of evolving drainage management paradigms and facilitates cross-disciplinary integration, including urban hydrology, infrastructure engineering, and spatial planning (Snyder, 2019).

The literature search was conducted up to December 2025 through national and international scientific databases, including Scopus, ScienceDirect, Google Scholar, as well as the Garuda and SINTA portals for accredited national journals. The keywords consisted of combinations of English and Indonesian terms, including "urban drainage performance," "stormwater management," "urban flood mitigation," "sustainable urban drainage system (SUDS)," "urban drainage resilience," "drainase perkotaan," and "risiko genangan." Boolean operators (AND, OR) were employed to systematically broaden and refine the search results in accordance with structured literature review procedures (Kitchenham, 2004).

The reviewed literature was limited to publications from 2000 to 2025 to capture the conceptual evolution of modern drainage management and urban resilience approaches. Nevertheless, several classical references in hydrology and drainage were retained as foundational theoretical sources. The inclusion criteria comprised: (1) nationally and internationally indexed journal articles addressing drainage system performance or urban runoff management; (2) studies examining green infrastructure approaches, source control measures, or drainage system resilience concepts; (3) relevant books and technical guidelines; and (4) publications in Indonesian or English. Articles not directly related to urban drainage systems or those of a purely opinion-based nature were excluded from the selection process.

The literature selection process involved three primary stages: initial identification based on keywords, screening of titles and abstracts, and comprehensive full-text review to ensure alignment with the research focus. Selected studies were analyzed to identify drainage system performance indicators, capacity enhancement strategies, and integration models between gray infrastructure and green infrastructure.

The analysis employed a thematic synthesis approach by categorizing findings into three principal themes: (1) performance indicators and parameters of drainage systems; (2) strategies for improving system capacity and efficiency; and (3) resilience and adaptation approaches to evolving urban hydrological characteristics (Thomas & Harden, 2008). A conceptual synthesis was subsequently developed to formulate strategic implications relevant to drainage system development in Bone Regency, taking into account the characteristics of a developing region and the dynamics of expanding built-up areas.

To ensure the credibility of the review, source triangulation was conducted by comparing findings from international and national literature and identifying consistent patterns in performance enhancement strategies. Interpretation was carried out analytically and reflectively to ensure that the resulting conceptual framework possesses both strong

theoretical grounding and contextual relevance.

Through this methodology, the study is expected to generate a comprehensive synthesis of strategies for improving urban drainage system performance and to provide a conceptual foundation for adaptive, systemic, and risk-oriented drainage planning in Bone Regency.

RESULT AND DISCUSSION

Based on the literature search and synthesis described in the methodology, several conceptual and strategic approaches were identified as relevant to enhancing the performance of urban drainage systems. The analysis was conducted thematically to determine key patterns in the literature related to system performance evaluation, runoff control strategies, and resilience-oriented drainage management. The synthesis indicates that improving drainage system performance cannot be understood as a single technical intervention; rather, it requires a systemic approach integrating hydrological, structural, and spatial planning dimensions.

The discussion is organized into three principal sections aligned with the research objectives: (1) a performance-based approach to urban drainage evaluation; (2) integration of gray and green infrastructure to reduce inundation risk; and (3) the application of resilience principles in long-term drainage planning. These sections are analyzed with reference to urban hydrology theory, performance-based system concepts, and urban drainage resilience frameworks introduced earlier. Accordingly, this section not only summarizes the literature but also develops a conceptual synthesis relevant to drainage system development in Bone Regency.

Performance-Based System Approach in Urban Drainage Evaluation

The literature synthesis demonstrates that improving urban drainage performance can no longer be equated merely with enlarging channel dimensions or expanding drainage networks. Conceptually, system performance must be evaluated using measurable hydrological and hydraulic indicators, such as peak discharge, time of concentration, inundation area and depth, and drain-down time (Ashley et al., 2007; Butler & Davies, 2011). Within the framework of urban hydrology theory (Chow et al., 1988; Tucci, 2007), the expansion of impervious surfaces increases runoff coefficients and accelerates hydrograph response, often causing existing drainage systems to be undersized relative to actual discharge conditions.

The literature further indicates that a performance-based approach enables the identification of critical system failure points through integrated hydrological–hydraulic modeling (Suripin, 2016). This perspective aligns with systems theory, which conceptualizes drainage as an interconnected network comprising primary and secondary channels, retention ponds, and receiving water bodies. Consequently, performance enhancement should not be confined to isolated channel segments but must address overall system efficiency.

In relation to the research objectives, these findings affirm that performance improvement strategies must be grounded in comprehensive system evaluation rather than partial or localized interventions.

Integration of Gray and Green Infrastructure

A consistently emphasized strategy in the literature is the integration of structural (gray) infrastructure and nature-based (green) solutions. Fletcher et al. (2015) and Ahiablame et al. (2012) argue that channel enlargement without runoff control at the catchment scale merely transfers inundation risk downstream. Sustainable Urban Drainage Systems (SUDS) therefore promote peak flow reduction through infiltration wells, bioretention systems, permeable pavements, and functional green open spaces.

Theoretically, this approach corresponds with the source control concept in urban hydrology, which seeks to reduce runoff volume and velocity before it enters the main drainage network (Butler & Davies, 2011). Integration of green and gray infrastructure reduces hydraulic loading on primary channels and enhances overall system efficiency. National studies demonstrate that combining retention ponds with infiltration systems significantly reduces peak discharge compared to purely conventional structural approaches (Yuliani et al., 2019; Salim et al., 2020).

Accordingly, system-based drainage performance enhancement requires a hybrid strategy that combines structural capacity improvements with upstream runoff control measures.

Urban Drainage Resilience Approach

Beyond performance-based evaluation, the literature underscores the importance of resilience in urban drainage systems. Meerow et al. (2016) and Mugume & Butler (2017) define resilience as the capacity of a system to absorb disturbances, adapt to change, and recover following extreme events. In drainage contexts, resilience encompasses design flexibility, network redundancy, and adaptive capacity to accommodate increasing rainfall intensity and expanding urbanization.

This approach is particularly relevant under conditions of climate uncertainty and rapid urban growth. Drainage systems designed solely on historical rainfall data, without accounting for future development scenarios, face heightened risks of functional failure. Consequently, performance improvement strategies must incorporate flexibility and adaptive capacity principles, such as modular design and provision for future system expansion.

In relation to the research objectives, resilience broadens the understanding of performance enhancement beyond immediate efficiency toward long-term system sustainability.

Strategic Implications for Bone Regency

The conceptual synthesis yields three principal implications for Bone Regency. First, a comprehensive evaluation of existing system performance through hydrological and hydraulic analysis is essential to identify actual capacity and critical inundation points. Second, the implementation of green infrastructure in developing areas—such as infiltration wells and functional green open spaces—can reduce runoff loads before they enter the primary drainage network. Third, resilience principles should be embedded in long-term drainage planning, including consideration of urban growth scenarios and projected increases in rainfall intensity.

Bone Regency's physical characteristics, including a combination of lowland and coastal areas, increase the likelihood of runoff accumulation if conveyance systems are suboptimal.

Therefore, a system- and resilience-based approach is particularly relevant to ensure that drainage infrastructure development is proactive and adaptive rather than reactive to emerging inundation problems.

Overall, the findings demonstrate that strategies for improving urban drainage system performance should rest upon three fundamental pillars: (1) performance indicator-based system evaluation; (2) integration of gray and green infrastructure; and (3) application of resilience and long-term adaptation principles. These pillars are mutually reinforcing and collectively form a comprehensive performance enhancement framework.

Accordingly, this study addresses the research questions outlined in the introduction by identifying system- and resilience-based performance improvement approaches, analyzing effective strategies for reducing inundation risk, and formulating conceptual implications applicable to Bone Regency.

CONCLUSION

Based on the synthesis of the literature, improving the performance of urban drainage systems can no longer be understood merely as a conventional effort to increase channel capacity. Instead, it must be grounded in a performance-based approach. System evaluation should be conducted comprehensively using hydrological and hydraulic indicators, such as peak discharge, inundation extent and duration, and drain-down time. This approach enables the systematic identification of critical failure points and provides a rational basis for formulating more effective technical interventions.

Moreover, effective strategies for reducing inundation risk require the integration of structural (gray) infrastructure and nature-based (green) solutions. Runoff control at the source through infiltration wells, retention ponds, and functional green open spaces has been shown to reduce hydraulic loading on primary drainage networks and enhance overall system efficiency. This approach aligns with the source control concept in urban hydrology and strengthens the system's capacity to manage runoff in a sustainable manner.

Furthermore, the application of urban drainage resilience principles constitutes a crucial element of long-term drainage planning. Systems that are adaptive, flexible, and incorporate network redundancy are better equipped to cope with uncertainties arising from urban expansion and increasing rainfall intensity. In the context of Bone Regency, a performance- and resilience-based approach implies the necessity of comprehensive evaluation of existing systems, integration of runoff control measures within spatial development planning, and drainage design that accounts for future urban growth dynamics. Thus, enhancing drainage system performance should not only aim at reducing present inundation risks but also at ensuring long-term sustainability and resilience.

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