Opportunities for Transformative Governance for Nature-based stormwater Solutions (NBSsw): baseline approaches

Opportunités pour une gouvernance transformatrice des solutions fondées sur la nature pour la gestion des eaux pluviales (NBSsw) : approches de référence

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RÉSUMÉ

Bien que les solutions fondées sur la nature soient reconnues pour leur potentiel à atténuer les inondations, améliorer la qualité de l'eau et renforcer l'habitabilité urbaine, leur mise en œuvre à grande échelle demeure limitée par des défis de gouvernance, de financement et de suivi. Les SFn-e sont définies ici comme des mesures de gestion des eaux pluviales alignées sur les processus écologiques, apportant une valeur significative en biodiversité et des co-bénéfices hydrologiques, sociaux et environnementaux, avec une faible empreinte carbone sur leur cycle de vie. Cela contraste avec les systèmes fortement ingénierisés, étanchéifiés ou souterrains, à fonctionnalité écologique minimale.

Cet article présente trois résultats principaux. Premièrement, une analyse comparative de Copenhague, Paris et Athènes montre que, bien que les trois villes déploient des SFn-e, leurs stratégies diffèrent nettement. Deuxièmement, un cadre d'évaluation liant hydrologie, biodiversité et carbone est opérationnalisé et démontré dans divers contextes urbains. Troisièmement, plusieurs leviers institutionnels transversaux — investissements à long terme, coordination multisectorielle et normes fondées sur la performance — sont identifiés pour accélérer la transition vers des régimes de gestion des eaux pluviales fondés sur la nature. Ensemble, ces résultats offrent une base solide pour co-élaborer des trajectoires de transition avec des partenaires locaux face aux scénarios climatiques futurs.

ABSTRACT

Although nature-based solutions are widely recognised for their potential to mitigate flooding, improve water quality, and enhance urban liveability, large-scale implementation remains constrained by governance, funding, and monitoring challenges. NBSsw are defined here as stormwater measures that operate in alignment with ecological processes, provide meaningful biodiversity value, and deliver hydrological, social, and environmental co-benefits with a low life-cycle carbon footprint. This contrasts with heavily engineered, sealed, or underground systems that offer minimal ecological function.

This paper presents three main results. First, a comparative analysis of Copenhagen, Paris, and Athens reveals that, while all three cities deploy NBSsw, their strategies differ significantly. Second, an NBSsw assessment framework is operationalised, linking hydrology, biodiversity, and carbon, and its applicability is demonstrated across diverse urban contexts. Third, several cross-cutting institutional levers, including long-term investment pipelines, multi-sector coordination, and performance-based standards, are identified as mechanisms to accelerate transitions toward nature-based stormwater regimes. Collectively, these findings establish a robust foundation for co-developing transition pathways with local partners under future climate scenarios.

KEYWORDS

(Biodiversity, Governance mechanisms, Nature-based solutions (NBS), Stormwater management, Urban resilience)

1 INTRODUCTION

This study examines how European cities facing increasingly frequent cloudbursts and heatwaves can transition from fragmented, grey stormwater control towards integrated, nature-based stormwater solutions (NBSsw) that enhance long-term climate resilience. Recent reviews of NBSsw emphasize their capacity to reduce flood risk, improve water quality, and support the development of liveable, low-carbon cities. However, these reviews also identify persistent implementation challenges related to governance, funding, and monitoring frameworks (Silveira et al., 2025; Santos, 2025; de Rijke et al., 2025; Fang et al., 2023).

We define **nature-based stormwater solutions (NBSsw)** as measures that: (1) are inspired by and work with ecological processes; (2) contribute positively to biodiversity conservation; (3) re-establish a more natural urban water balance; (4) deliver high water-quality outcomes; (5) maximize social and environmental co-benefits, such as cooling, recreation, and improvements to public mental and physical health; and (6) maintain a low life-cycle carbon footprint, verified through materials and maintenance assessments (Silveira et al., 2025; Fang et al., 2023). In contrast, "non-nature-based" stormwater measures are those that rely primarily on sealed, underground, or heavily engineered assets (e.g. pipes, including separated sewage systems, storage tunnels, end-of-pipe tanks, detention basins, stormwater pumping stations) that provide minimal habitat value, have a substantial carbon footprint, and address only a narrow, single-scoped resilience target (Santos, 2025).

Our contribution is threefold. First, we integrate governance and technical perspectives to characterise how NBSsw are currently conceptualised and implemented in three European cities: Copenhagen, Paris, and Athens, each representing a distinct position along a gradient of climatic and hydrological extremes. Second, we develop a working definition of NBSsw that explicitly connects hydrological performance, biodiversity support, and life-cycle carbon considerations, drawing on recent assessments and reviews of blue and green infrastructure, NBSsw, and climate hazard management (de Rijke et al., 2025; Ooms et al., 2025). Third, we identify both city-specific and cross-cutting institutional factors that enable or constrain transitions toward a city-wide, nature-based stormwater regime, thereby complementing existing case studies of NBS governance and experimentation in Copenhagen and other contexts (Jørgensen et al., 2022; Morgado et al., 2025).

2 METHODS

This study employs a living-labs approach to stormwater management and climate adaptation in Copenhagen, Paris, and Athens. A qualitative comparative analysis is conducted on municipal climate adaptation and drainage strategies, zoning codes, technical standards, and major project documents, with a focus on the definition, prioritization, and spatial targeting of NBSsw. The documentary analysis is supplemented by a structured review of local plans and demonstrator projects reported in the peer-reviewed literature, particularly those addressing Copenhagen's cloudburst management, Parisian greening and cooling strategies, and Athens' emerging green roof and street-greening programs (Jørgensen et al., 2022; Morgado et al., 2025; Azmeer et al., 2024; Spyrou et al., 2024). Recent systematic reviews are used to contextualize these local trajectories within broader debates on NBSsw and climate hazard mitigation (de Rijke et al., 2025; Fang et al., 2023).

3 RESULTS

A comparative baseline indicates that all three cities now reference Nature-Based Solutions (NBS) and Blue and Green Infrastructure in their climate adaptation narratives, although their approaches differ significantly. Copenhagen provides one of the earliest examples of translating climate strategies into district-scale plans that integrate green streets, detention boulevards, and multifunctional public spaces. However, financial and regulatory frameworks continue to prioritize large grey infrastructure, resulting in a skewed water balance, while biodiversity and life-cycle carbon considerations remain marginal or absent in decision-making (Jørgensen et al., 2022; Morgado et al., 2025; Santos, 2025). Paris sets ambitious targets for cooling, tree planting, and surface greening. Modelling of greening scenarios demonstrates strong potential for improving thermal comfort and achieving energy savings, yet stormwater and water-quality objectives are only weakly integrated into these initiatives (Azmeer et al., 2024; de Munck et al., 2018, cited in de Rijke et al., 2025). Athens is at an earlier stage of development: NBS are mainly presented as heat-mitigation and amenity measures, with a focus on green roofs as a cooling strategy. Stormwater management, water quality, and systemic connectivity are only beginning to receive attention (Khan et al., 2022; Marando et al., 2021; Spyrou et al., 2024).

Across all three cases, several broader patterns align with findings from recent European reviews. NBSsw are frequently implemented as project-level features, most of which remain in the testing phase, rather than being

integrated as core components of the drainage system. Performance indicators typically emphasize peak-flow reduction rather than the overall urban water balance, with limited consideration for long-term maintenance, ecosystem service delivery, or distributional equity. Furthermore, institutional arrangements for financing, monitoring, and cross-sector coordination often lag behind technical ambitions (Santos, 2025; de Rijke et al., 2025; Fang et al., 2023). Concurrently, emerging empirical studies, such as quasi-experimental evaluations of municipal adaptation measures in Amsterdam, demonstrate that combined portfolios of NBS and other interventions can substantially reduce insured damages from heavy rainfall, thereby reinforcing the rationale for mainstreaming NBSsw in climate adaptation strategies (Ooms et al., 2025).

4 DISCUSSION AND IMPACT

We argue that Copenhagen, Paris, and Athens are each developing distinct "NBSsw regimes" that reflect their respective climatic exposure, institutional histories, and planning cultures. Copenhagen demonstrates a rapid response to climate change, as evidenced by the implementation of the Copenhagen Cloudburst Adaptation Plan less than one year after the extreme event of July 2, 2011. However, this plan does not qualify as an NBSsw because it operates alongside the existing combined sewer system, together managing rainfall up to the 100-year event, without consideration for carbon footprint, potential ecosystem services, broader climate resilience, or social justice. This approach reflects a path-dependent reliance on grey infrastructure, with vegetation serving primarily as decorative elements (Jørgensen et al., 2022; Morgado et al., 2025). Paris illustrates both the opportunities and risks of prioritizing cooling, liveability, and greening agendas in NBS initiatives, while not fully realizing their hydrological and ecological potential (Azmeer et al., 2024). Athens exemplifies the challenge and urgency of integrating heat-oriented greening with stormwater management, water quality, and biodiversity objectives in a context of limited resources and high climate risk, yet lacks concrete implementation plans (Khan et al., 2022; Marando et al., 2021; Spyrou et al., 2024). These findings collectively indicate that advancing robust NBSsw regimes will require not only technical design improvements but also governance innovations in finance, regulation, and cross-sector collaboration (Santos, 2025; de Rijke et al., 2025).

5 NEXT STEPS

Building on this baseline, the research will move forward with local partners in Copenhagen, Paris, and Athens to develop ways to shift from today's mixed grey-green systems to city-wide NBSsw regimes. The planned work includes: (1) refining a practical typology and indicator set for NBSsw that measures hydrological performance, biodiversity support, and life-cycle carbon; (2) identifying institutional barriers and opportunities for changing investment and regulatory frameworks; and (3) testing scenario-based methods for sequencing NBSsw portfolios under different climate and socio-economic conditions, using recent advances in NbS assessment and transition governance (Santos, 2025; Silveira et al., 2025; Ooms et al., 2025; de Rijke et al., 2025). This paper provides both a data-driven comparison of three European cities and a framework for understanding and managing the rise of nature-based stormwater regimes during climate extremes.

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