NATURGO
NATURE BASED SOLUTIONS AND URBAN WATER GOVERNANCE

Lessons from literature and case studies on cities and NBS related water governance

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SUMMARY

This report synthesizes current insights from scientific literature and practical case studies on the governance of nature-based solutions (NBS) related to water in urban contexts. It is developed to inform and guide the engagement with the partnering cities and the planning and governance strategies of the NATURGO project, particularly the Work Packages 3, 4 and 5.

In exploring the NBS in urban water systems from a both strategic and practical implementation perspective, the report has five core objectives: (1) to identify leading/promising governance and planning approaches that promote NBS in cities; (2) to understand which phases of the management cycle (goal-setting, analysis, strategy formation, strategy implementation and strategy monitoring) are most critical; (3) to determine the metrics and indicators used to evaluate the effectiveness of interventions on NBS water governance; (4) to analyse barriers and enablers that influence successful implementation of NBS in urban water systems; and (5) to map best practices from diverse urban contexts, including examples relevant to NATURGO case study cities.

The report reveals that while enthusiasm for NBS has been growing, successful uptake is far from automatic or widespread. It depends on context-sensitive governance arrangements and steps in coordinating various factors. Much remains unknown about how fragmented mandates play out in practice, how participatory processes can genuinely shift power, how durable collaborative structures are best designed, how decision-making under uncertainty can be supported, and how financing and scaling challenges can be addressed through governance innovations. Effective NBS implementation requires interdisciplinary and transdisciplinary collaboration, strong engagement among the stakeholders, and innovative technological approaches. Addressing barriers such as institutional fragmentation, financial constraints, and capacity gaps is crucial, while leveraging enablers like policy support, stakeholder engagement, and long-term financial planning ensures sustainability. Additionally, continuous monitoring and adaptive management are essential for assessing the effectiveness of NBS projects and ensuring their long-term resilience against climate change impacts.

The report highlights the importance of multi-level governance, which involves coordination across local, national, and international levels to align policies and strategies. Recognizing and valuing the full spectrum of ecosystem services provided by NBS helps gain public and political support, driving funding and resource allocation towards NBS projects. Academic debates on the transition to urban water NBS revolve less around acknowledging its complexity, which is widely

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recognised, and more around how to address unresolved issues: overcoming institutional fragmentation, ensuring participation translates into equity and empowerment, agreeing on metrics for effectiveness, and reforming policy and financing structures to support long-term mainstreaming.

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ACRONYMS

NBS	Nature-Based Solutions
BGI	Blue-Green Infrastructure
SUDS	Sustainable Urban Drainage Systems
WSUD	Water-Sensitive Urban Design
EbA	Ecosystem-Based Adaptation
GI	Green Infrastructure
CW	Constructed Wetlands
WSC	Water Sensitive Cities
UWWR	Urban Wastewater Recycling
UA	Urban Agriculture
FEW	Food, Energy, and Water

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1 INTRODUCTION

Urbanization, population growth, and climate change are placing unprecedented pressure on urban infrastructure systems, challenging the sustainability of conventional approaches to city planning and development. Throughout history, cities have also been undergoing shifts in managing urban water services, reflecting the dominant perceptions of what is good and possible, relying strongly on technological and organisational possibilities of the time.

The dominant focus of cities has until recently been on “grey infrastructure” - the construction of dams, pipelines, extensive sewer networks and large-scale engineering solutions. Historically, engineers have designed these systems to ensure reliable water supply and sanitation, prioritizing technical efficiency and public health over ecological considerations. The technical code of grey infrastructure embodies values of mastery and separation from nature, reinforcing the idea that water must be disciplined and managed through technological means to support urban development and modern lifestyles (Bell, 2015). Approaching water as a resource to be harnessed and controlled for human use is deeply rooted in a technical framing of water problems, emphasizing control and domination over natural water systems. This paradigm has led to significant environmental impacts, including the degradation of aquatic ecosystems and high energy consumption, highlighting the need for a shift towards more sustainable and integrated water management practices (Bell, 2015).

Urban water infrastructure has evolved significantly over time, marked by distinct phases. In the 19th century, cities focused on developing basic water supply systems to provide clean drinking water and improve public health. By the late 1800s and early 1900s, the emphasis shifted to building sewer systems to manage wastewater and prevent waterborne diseases. From the mid-1900s, urban drainage systems were designed to quickly remove stormwater from cities to prevent flooding. Starting in the 1970s, there was a growing awareness of the environmental impacts of urban drainage (Bertrand-Krajewski, 2021; Brown et al., 2009). Since the 1990s, integrated water management approaches have become more prevalent, focusing on managing water supply, wastewater, and stormwater as interconnected systems to maximize sustainability and resource efficiency (Larsen et al., 2016). The most recent phase aims to fully integrate water management into urban planning and design, emphasizing the role of water in creating liveable, resilient, and sustainable cities (Koop et al., 2022).

The development of nature-based solutions (NBS) can be traced back to the early concepts of managing natural resources and enhancing ecosystem functions to

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reduce habitat loss and increase ecosystem services (Cohen-Shacham et al., 2019). Between 1990 and 2000, research primarily focused on forest restoration and ecological engineering, which were early predecessors of the NBS terminology. The transition to a more explicit link between nature and human well-being began around 2000 with the development of the ecosystem services approach, eventually leading to the NBS concept. This shift was further solidified in 2010 with the establishment of funding sources like the Green Climate Fund, which altered thinking towards the coexistence of people and nature (UNFCCC, 2011). The priorities in research funding, particularly through the Horizon 2020 program starting in 2015, facilitated more holistic thinking and substantial increases in NBS research across Europe. This period marked a significant transition as NBS began to be formally recognized for their potential to address a range of societal challenges beyond climate change mitigation and biodiversity loss (IUCN, 2020).

NBS present themselves as a promising alternative, offering interventions that mimic natural processes to address these challenges while delivering multiple co-benefits. Over the past years, NBS has grown into a widely-adopted term that encompassed concepts of achieving sustainable, harmonious, and green development, and synergized human and environmental outcomes (Cohen-Shacham et al., 2019). Urban NBS offer opportunities to tackle these challenges by integrating ecological systems into urban planning and governance. NBS, defined as actions to protect, manage, and restore ecosystems while addressing societal challenges, provide co-benefits such as climate resilience, biodiversity enhancement, and improved human well-being.

Box 1: Definition of NBS
"Actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits" (United Nations Environment Assembly of the United Nations Environment Programme, 2022, p. 2).

Cities are increasingly recognized as innovation hubs and critical arenas for addressing global sustainability challenges, including climate change, biodiversity loss, and sustainable resource consumption (e.g., OECD, 2023; IUCN, 2020; EEA, 2017, SEI, 2022). However, mainstreaming NBS into urban governance remains a complex process requiring systemic shifts in planning paradigms, institutional structures, and multi-level governance landscapes (Adams et al., 2024). NBS are important sustainability solutions for cities because they can produce multiple co-

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benefits in these inter-linked systems (Frantzeskaki & McPhearson, 2022), requiring multiple changes across technological, economic and social factors, including goals, approaches and metrics.

Apart from new technologies, NBS also represent new systems of decision-making, planning and governance, and new ways of assessing the success of their utility. Change in the institutions, paradigms, and principles that govern, plan, and build cities usually takes a long time to be realised. Norms, rules, and the way we think about urban nature require long-term, strategic, and adaptable processes that are supported by communities and policies across the multi-level governance landscape of cities. This insight is in part based on the acknowledgement that mainstreaming does not just happen in practice or in policy and it is not just about the actions of a small number of individuals. It occurs across multiple domains, including in the political sphere, and across the multi-level governance landscape of cities.

The report primarily serves the project NATURGO and its partners in contextualising the work planned in the project and situating it in ongoing debates at the theoretical and practical level. It provides a comprehensive analysis of the governance and strategic approaches related to promoting urban water management and NBS. The objectives of the report are a) to identify the main governance, planning, and strategic frameworks that facilitate the integration of NBS into urban environments. Additionally, b) to list the critical management phases, such as planning, implementation, and monitoring, that are essential for the successful deployment of NBS and in guiding cities through the complexities of policy-making, stakeholder engagement, and resource allocation; c) to determine the metrics and indicators currently used to assess the performance of NBS initiatives, used to measure the effectiveness of the initiatives by cities, track progress, and evaluate the success and impact of NBS projects; d) to identifying the barriers and enablers that influence the successful implementation of NBS, faced by urban planners and policymakers. Finally, this report maps out best practices in NBS governance, with a particular focus on urban contexts similar to the NATURGO case study cities. By examining these best practices, the aim is to offer practical recommendations and strategies that can be adopted by other cities to enhance their NBS governance and achieve sustainable urban development.

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2 METHODS

We conducted a scoping review from academic and grey literature. From academic literature, we used the search engine Scopus under the category of »title-abstract-keywords«. The following search string was applied in April 2025:

urban OR cities OR city OR town OR municipalit* OR suburban AND	water OR stormwater OR rainwater OR wastewater OR sewage OR hydrology AND	governance OR governing OR "decision making" OR decision-making OR policy OR management OR planning OR implementation OR institutions OR regulation OR "policy making" AND	nature-based* OR "nature based" OR NBS OR "ecosystem services" OR integrated OR circular OR decentralised OR "sustainable urban drainage" OR SUDS OR "water-sensitive urban design" OR "green infrastructure*" OR "blue infrastructure*" OR "above ground infrastructure*" AND	Transition* OR Transformation*

The search resulted in a total of 1052 papers in the English language. After applying filters to assess the relevance of the title and abstract to the topic of urban water NBS, 576 articles were retrieved, which constitutes 55% of all found papers published since 2015. In this report, 100 of the most relevant papers were included in the full-text reading. The full list of articles found with the search string and included in the review is found in **ANNEX 1**. Case studies are distributed throughout the report, providing tangible content that illustrates practical applications and outcomes of water NBS.

We searched for grey literature using the OpenAlex database and Google Search, using the same keywords as for the article search. This resulted in 96 reports, which

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were screened and 33 were included in the report. The full list of reports found with the search string and included in the review is found in **ANNEX 2**.

Papers and grey literature were reviewed between March and June 2025 by two readers in created categories: Views, structures and practices; Scale/perspective/level of governance; Management phases; Co-design; Actors; Enablers; Barriers; Indicators/Metric; Knowledge gaps; Case studies. After the reading the analysis in each category was performed and this report prepared.

We conducted a search within the Urban Nature Atlas database. We applied specific filters to narrow down the results: the challenges addressed were set to "water management". This search yielded a total of 729 projects. From these, we selected 50 projects to ensure a diverse and representative sample. Out of these 50, we included 20 projects in the report, providing detailed descriptions of their values and contributions to sustainable urban water management. The full list of projects from Urban Nature Atlas is found in **ANNEX 3**.

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3 NOTE ON TERMINOLOGY

Our search string aimed to capture a broad literature pertinent to the field. The articles belong to different bodies of literature. Diverse terms were found in the literature for similar concepts. For example, "Nature-Based Solutions" (NBS) and "Ecosystem-Based Adaptation" (EbA) both refer to strategies that leverage natural processes to address environmental challenges. Similarly, "Blue-Green Infrastructure" (BGI) and "Sustainable Urban Drainage Systems" (SUDS) describe approaches to managing urban water through natural and engineered systems. "Water-Sensitive Urban Design" (WSUD) and "Constructed Wetlands" (CW) are terms used to denote designs that integrate water management with ecological principles, each brining attention to a specific aspect. Our analysis aimed to draw general lessons from the literature, rather than point to dissimilarities, and to highlight common features in concepts rather than single out specific ones over others.

These terms represent transformational lines of sight generated by Bulkeley et al. (2023) and are all part of a broader discourse that reimagines the relationship between nature, water, and urban environments. Each term brings a slightly different conceptual approach but shares a common goal: to integrate natural processes into urban systems to address pressing environmental challenges, particularly those related to water management and climate resilience. NBS and EbA both emphasize the power of ecosystems to solve urban environmental problems. NBS focuses on harnessing nature's ability to address a range of challenges (e.g., flooding, air quality, and heat islands), positioning nature as a partner in sustainable urban development. EbA, on the other hand, focus on climate adaptation, stressing the role of ecosystems in helping cities cope with climate change, such as by restoring wetlands to buffer against flooding or protecting coastal habitats to reduce storm surge impacts. BGI and SUDS are terms specifically related to urban water management, but they blend natural and engineered systems. BGI conceptualizes water systems through a broader, integrated lens-fusing blue (water) and green (landscape/vegetation) elements to create multifunctional spaces that manage stormwater while also improving biodiversity, aesthetics, and public health. SUDS, in contrast, is more focused on hydrological engineering, where sustainable drainage solutions (such as permeable pavements or rain gardens) manage water runoff and reduce urban flooding. WSUD brings a design-centric approach to integrating water into urban planning. It goes beyond water management to reframe how water interacts with the urban fabric emphasizing the need for sustainable, efficient water use in everyday urban life and promoting solutions like rainwater harvesting, stormwater treatment, and water

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recycling. Constructed Wetlands, a more specific approach, conceptualizes water management through the lens of ecological engineering. Constructed wetlands replicate natural wetland functions such as water filtration, habitat provision, and flood mitigation, offering a tangible, NBS for urban water challenges.

Collectively, these terms reflect a shift in urban planning discourse, where the relationship between nature, water, and the urban environment is no longer seen in opposition but rather as interdependent. The focus is on moving away from traditional, grey infrastructure (such as concrete drainage and sewer systems) and towards systems that mimic natural processes, fostering resilience and sustainability. These concepts challenge the conventional view of cities as separate from nature, advocating for urban landscapes that work in harmony with ecosystems. By framing cities as dynamic, evolving systems that incorporate water, green spaces, and biodiversity, these terms open up new ways of thinking about urban resilience, sustainability, and the role of nature in modern cities.

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4 GOVERNANCE OF WATER NBS

This section aims to detail various aspects of the shift toward NBS-based water governance. As a whole, it aims to respond to the overarching question of »How does the shift to NBS-based governance occur in urban contexts?« and focusing on various aspects of the shift, as indicated in the Introduction (taking place across perceptions, institutions and specific policy or technological measures). Each of the observed aspects is analysed in turn.

The literature we captured belongs to diverse bodies of literature, which we divided into: governance, water management, urban planning, transition/transformation, nexus and circular economy, each of which provides different foci of the analysis. **The governance literature is concerned less with defining change itself, and more with how transitions are governed through institutional arrangements, power dynamics, coordination mechanisms, and adaptive processes (**Koohestani et al., 2025; Malekpour et al., 2021; Hölscher et al., 2023). Water management literature tends to focus more on the technical performance and operational design of introduced solutions, for example, assessing hydraulic efficiency, stormwater retention, or treatment capacity (Liu et al., 2019; Pearlmutter et al., 2019). Urban planning literature focuses on the spatial and infrastructural integration of NBS within the built environment, examining issues such as land-use constraints, densification, and the coordination of blue-green infrastructure with existing urban systems (Koohestani et al., 2025; Liu et al., 2019; Kabisch et al., 2016). Transition and transformation literature engages with processes of societal and institutional change, which may or may not be linked to sustainability agendas, and often without a fully systemic perspective. Where applied to urban water and NBS, this body of work highlights issues such as governance lock-ins, path dependencies, and the role of experimentation in creating openings for new practices (Malekpour et al., 2021; Hölscher et al., 2023; Albert et al., 2021). Nexus literature examines the interdependencies between water, energy, and food systems (Tsatsou et al., 2023), while circular economy research emphasizes resource recovery and recycling to establish closed-loop processes (Langergraber et al., 2020; Pearlmutter et al., 2019). Although many bodies of literature address more than one aspect such as combining technical performance with spatial planning, or linking governance with participation, these perspectives often remain only partially integrated. This highlights the need for approaches that deliberately connect technical, spatial, institutional, and social dimensions within a single analytical framework. For instance, governance literature often intersects with urban planning when discussing policy implementation and regulatory frameworks. Similarly, water management literature frequently overlaps with nexus and circular

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economy studies, particularly in the context of sustainable resource use and waste reduction. This multidisciplinary approach allows for a more holistic understanding of the challenges and opportunities associated with NBS. By integrating insights from various fields, researchers can develop more comprehensive strategies that address both the technical and socio-political dimensions of NBS implementation. Moreover, the transition/transformation literature provides valuable perspectives on the processes and pathways for achieving systemic change. This includes examining the drivers, barriers, and enablers of transformation, which are critical for scaling up NBS initiatives. Drawing simultaneously on these diverse bodies of literature is not about proving their interconnection which is already well established but about bringing complementary perspectives into one frame.

Three overlapping debates or entry points or focus areas organise most studies on water-NBS governance. The first body of literature is focussed on institutions and their ability to present either a vector of change or a source of path-dependency: in focussing on institutions, authors explore how change is driven by deliberate reform of rules, mandates and finance (e.g. Sponge City mandates or IUWM reforms; Shi et al., 2024; Keremane, 2015), and emphasise institutional inertia and lock-in of grey infrastructures that limit reform (Staddon et al., 2017; Langergraber et al., 2020). The second focus area are actors and their role in the multi-actor governance arena: here, studies examine whether polycentric, arrangements of shared responsibilities across municipal, private and community actors increase adaptability and legitimacy (Staddon et al., 2017; Casiano Flores et al., 2021), or instead create coordination problems and accountability gaps (Rogers et al., 2020; Knapik et al., 2024). The third focus area is the process of learning and its ability of co-production and democratization of society: here, research asks whether participatory, learning-based formats (LAAs, living labs) genuinely re-shape power and lead to durable institutional change, or whether they are ephemeral, depoliticised spaces that do not alter core regulatory incentives (Herslund et al., 2018; O'Donnell et al., 2018; Rodrigues & Antunes, 2021).

Empirical work has clustered around certain findings. A large body documents institutional fragmentation: separate mandates for stormwater, wastewater, drinking water and land use commonly produce gaps and blame-shifting (Malekpour et al., 2021; Langergraber et al., 2020). Case studies of policy reforms, e.g. Sponge City rules or SUDS permitting, show that legal mandates and planning codes can force mainstreaming when backed by fiscal instruments (Shi et al., 2024; McClymont et al., 2020). Other empirical work demonstrates that collaborative formal and informal networks (professional communities, LAAs) help create local legitimacy and problem-solving capacity, but these are often project-bound and fail to institutionalise (Herslund et al., 2018; Chaffin et al., 2019b; O'Donnell et al., 2018).

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Finally, finance-focused studies show repeated mismatch between short-term budgets and long-term NBS benefits; while blended finance and ecosystem valuation are proposed solutions, tested scalable financing pathways remain rare (Biswal & Balasubramanian, 2022; McClymont et al., 2020; Van Leeuwen et al., 2019).

4.1. Pathways to implementing urban water NBS

Research on NBS in urban water management highlights that cities must be understood as social–ecological–technical systems. Governance studies show that the success of NBS depends not only on technical design but also on how institutions, planning processes, and legal frameworks enable or constrain integration across scales. A consistent finding is that institutional fragmentation, with responsibilities for stormwater, wastewater, drinking water, land use and finance scattered across different agencies, creates significant barriers to coordination (e.g. Langergraber et al., 2020). This fragmentation prevents cities from adopting the holistic approaches needed to capture the multifunctional benefits of NBS. At the same time, many governance arrangements for NBS are ad hoc and project-based. Pilot projects may succeed through temporary collaborations or EU-funded experiments, but rarely do they translate into permanent structures embedded in municipal statutes or departmental mandates (Rogers et al., 2020). The literature repeatedly stresses the need for institutional reforms that shift from government to governance, creating durable cross-departmental mechanisms, participatory planning structures, and reflexive monitoring processes (IPBES, 2024). Another strand of research emphasises knowledge and capacity issues. Municipal staff often lack experience with NBS compared to conventional grey infrastructure, and training opportunities are limited. Studies point to weak knowledge transfer between experimental projects and mainstream practice, with insufficient monitoring data to support evidence-based scaling (Tsatsou et al., 2023). Similarly, valuation and financing remain underdeveloped: while the multifunctionality of NBS is recognised, economic frameworks and procurement systems are still geared towards single-purpose grey infrastructure, which discourages investment (Pineda-Martos et al., 2024). Finally, policy and regulatory environments are often misaligned with NBS characteristics. Standards for water reuse, stormwater management, or green infrastructure are either missing or based on conventional engineering assumptions. Procurement rules typically reward lowest-cost grey solutions rather than multifunctional NBS that deliver long-term resilience and co-benefits (Biswal & Balasubramanian, 2022). As a result, the mainstreaming of NBS into urban water governance remains slow and fragmented, despite growing awareness of their ecological, social, and economic potential.

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4.2. Organisation and governance

In the evolving landscape of urban water management, the integration of NBS has necessitated significant changes in organizational and governance structures. Changes in this cluster can be categorized into three main areas: changes to the rules and institutions, ways of cooperation, and ways of measurement. The three seem to interact / most of literature emphasises an interaction between three categories, but for the most part, no specific details are provided on how.

4.2.1.1. Changes to rules and institutions

The literature shows that successful mainstreaming of NBS depends less on technical breakthroughs than on institutional and regulatory reforms that reshape how urban water is governed.

One set of changes concerns the integration of NBS into statutory planning and permitting frameworks. The Sponge City initiative in China, for example, mandated the inclusion of green infrastructure in new developments and backed it with ecological compensation and public payment mechanisms (Shi et al., 2024). These reforms altered both land-use planning rules and fiscal arrangements, embedding ecosystem services into urban finance. Similarly, European cities experimenting with Sustainable Urban Drainage Systems (SUDS) have introduced building codes and stormwater regulations that require infiltration, detention or green roofs in new construction (McClymont et al., 2020). Such legal adjustments move NBS from voluntary add-ons to mandatory planning requirements.

Another important institutional shift is the move toward Integrated Urban Water Management (IUWM). This governance paradigm reframes water as a cycle rather than a linear supply-disposal system. Its implementation has required reforms in utility mandates, introducing demand management, stormwater harvesting, and wastewater reuse alongside conventional supply (Keremane, 2015; Malisa et al., 2019). These changes often entail revising water rights, clarifying ownership of reclaimed water, and introducing new pricing and tariff structures to incentivize conservation (Staddon et al., 2017). IUWM therefore represents both a technical and institutional reorientation of urban water utilities and regulatory agencies.

A further set of reforms relates to governance arrangements themselves. Staddon et al. (2017) describe the decline of centralized, corporatist water governance and the rise of “glocal” arrangements, where responsibilities are shared between municipal authorities, basin organizations, private firms, and communities. This restructuring has been reinforced by legal frameworks enabling public–private partnerships (Gabriel, 2016) and by new participatory planning requirements that

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legally oblige utilities or municipalities to involve citizens in decision-making (Casiano Flores et al., 2021).

Finally, institutional innovations have also occurred in the standardisation of monitoring and performance criteria. Some jurisdictions now require water utilities to apply environmental indicators (e.g. pollutant removal, infiltration rates, resilience metrics) alongside conventional technical standards (Zhang et al., 2022; Abd Aziz et al., 2023). This formalises ecological functions in regulatory assessment and creates incentives for utilities to adopt NBS. The literature highlights persistent gaps: most standards remain fragmented across sectors, and many countries lack harmonised rules for water reuse, hybrid systems, or multifunctional infrastructure (Shilky et al., 2024a; Ribarova et al., 2024).

These cases demonstrate that NBS mainstreaming is not only about design innovations but about changing the "rules of the game": land-use codes, water rights, tariff structures, utility mandates, procurement rules, and participation requirements. Where such reforms have been enacted, NBS have moved from isolated pilots to citywide programmes. However, the literature also points to uneven implementation and a lack of comparative evidence on the long-term effects of these institutional reforms. This is where NATURGO can add value: by systematically analysing how rule changes in different governance contexts enable or hinder NBS integration into water planning.

4.2.1.2. Ways of cooperation

Collaboration has emerged as one of the most central themes in the governance literature on NBS, but the way it is conceptualised and operationalised varies considerably. Academic work highlights not only the need for collaboration but also specific frameworks, mechanisms, and tensions that shape its effectiveness.

One prominent approach is the development of collaborative governance frameworks that bring together multiple stakeholders to co-design and implement NBS. Malekpour et al. (2021) argue that collaboration must be grounded in upfront planning, alignment of diverse interests, and adaptation to local contexts. Their contribution lies in linking collaboration with governance innovations such as transparency, experimentation, and new participatory mechanisms. Similarly, Casiano Flores et al. (2021) examine how collaborative approaches help overcome siloed institutional structures in water management, although they also point out that fragmentation and legal constraints often undermine coordination.

Specific institutional innovations have been tested. The Learning and Action Alliance model, for instance, has been used in stormwater management and climate adaptation projects to create spaces for trust-building, joint problem-solving, and

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iterative learning (Herslund et al., 2018; O'Donnell et al., 2018). These studies show that LAAs can enable social learning and co-production of knowledge, but they also highlight difficulties in sustaining these alliances once project funding ends. This exposes a gap: collaborative mechanisms are often short-lived and insufficiently institutionalised, leaving cities without durable structures for continued cross-sector work.

Other research looks at the role of informal networks. Chaffin et al. (2019b) demonstrate how informal collaborations between professionals across government, NGOs, and academia can fill governance gaps, fostering innovation in stormwater management where formal institutions are constrained. Dobre et al. (2018) similarly show that hybrid governance arrangements, where formal institutions collaborate with informal networks, influence the choice of soft, green, or grey measures. These contributions enrich the academic debate by emphasising that collaboration is not confined to formal governance structures but also relies on relational and networked forms of coordination.

At the community scale, research demonstrates the importance of grassroots participation in enhancing urban resilience. Alexandre (2018) shows how green infrastructure projects that leveraged community involvement improved flood resilience, while Rodrigues & Antunes (2021) stress that sustained behavioural change requires continuous citizen engagement and empowerment. These works underscore that collaboration is not just about institutional actors but also about embedding NBS in social practices and everyday life.

4.2.1.3. Ways of measurement

Indicators are the most common method of assessment. Environmental indicators such as stormwater volume reduction, pollutant removal efficiency, infiltration rates, and biodiversity indices are widely used to demonstrate technical performance and ecological co-benefits (Biswal & Balasubramanian, 2022; Palermo et al., 2023; Sun et al., 2024). Their added value lies in making ecological services tangible and comparable to grey infrastructure benchmarks, although gaps remain in long-term monitoring and standardisation (Zhang et al., 2022). Social indicators including park usage, quality of life indices, and stakeholder participation rates have been used to capture public perceptions, well-being, and equity outcomes (Gabriel, 2016; Malisa et al., 2019; O'Donnell et al., 2018). They add value by highlighting the societal acceptance of NBS, but their integration into planning decisions remains limited. Economic indicators such as cost–benefit ratios, avoided costs, and employment generation make a financial case for NBS (Malekpour et al., 2021; Van Leeuwen et al., 2019), often undervalue multifunctional benefits due to methodological limitations. Governance indicators, such as measures of collaboration

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effectiveness, policy integration, or network analysis, are used to evaluate enabling frameworks (Johannessen & Mostert, 2020; Chaffin et al., 2019a).

Alongside indicators, studies employ a growing set of technical and digital tools. Multi-criteria decision-making techniques (e.g. AHP, PROMETHEE) have been used to rank NBS options based on environmental, social, and economic criteria, offering structured support for complex planning choices (Abd Aziz et al., 2023). Spatial and statistical analyses are applied to measure green cover, open space distribution, and links between urbanisation and ecosystem services (Miroshnyk et al., 2022). Decision support tools, such as hydrological simulation models and sustainability dashboards, integrate data on stormwater flows, water quality, and land use to test scenarios and optimise interventions (Adem Esmail & Suleiman, 2020; Z. Sun et al., 2024). System Dynamics Modelling has been applied to analyse the Food–Energy–Water (FEW) Nexus, highlighting the interdependencies between water infrastructure, resource recovery, and socio-economic systems (Francisco et al., 2023). Tools like the Infrastructure Transition Canvas (ITC) help identify key actors, resources, and coordination tasks, thereby linking technical assessment with institutional design (Hohmann et al., 2025). Living labs and experimental platforms are increasingly adopted as governance-oriented methods for measurement. Urban living labs, such as the São Paulo FEW Nexus Laboratory, integrate decision-support tools with stakeholder networks, enabling co-design and iterative testing of NBS (Soares Dal Poz et al., 2022a).

4.3. Governance levels

Municipalities, cities, or local governments play a critical role in planning and executing NBS projects, often in collaboration with community stakeholders. Cities or local governments who are instrumental in planning and executing NBS projects, often collaborate with other community stakeholders to integrate place-based and systemic approaches to urban sustainability and resilience (Malekpour et al., 2021).

Unit of decision making

Local governance that succeeds in introducing NBS in urban water management, as observed in cities like Philadelphia, Kyiv, or the City of Bayswater in Western Australia, involves interdisciplinary perspectives that combine spatial analysis, environmental policy, and ecosystem services to address urban challenges across environmental, social, and governance aspects (Gabriel, 2016; Maher, 2020; Miroshnyk et al., 2022; Sulieman et al., 2025). These efforts also include transdisciplinary collaborations that engage policymakers, urban planners, and local communities (Sulieman et al., 2025). Similarly, in São Carlos, Brazil, resilience-driven perspectives are adopted at the catchment level, focusing on

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urban planning and infrastructure development (McClymont et al., 2020). Municipalities in southern China focus on basin-level governance to address water management challenges (Hao et al., 2015). This approach is observed in various urban areas, such as individual buildings, sites, and cities, where green building materials and systems are integrated to enhance ecosystem services and promote circular economy principles (Pearlmutter et al., 2020).

Level of coordination across sectors within the city

Local governance that succeeds in introducing NBS in urban water management involves interdisciplinary and transdisciplinary collaborations. These collaborations engage policymakers, urban planners, and local communities to ensure sustainable solutions that effectively address local needs (Sulieman et al., 2025). Local governance is also observed in cities in the Valencian region of Spain, where the focus is on urban circularity challenges (Perales-Momparler et al., 2017). Municipalities like Linz, Austria, and Toulouse, France, emphasize district-wide governance involving local councils, real estate developers, and professionals in stormwater management (Gimenez-Maranges et al., 2023).

Level of coordination between city, national and international policies

Regional and national authorities support local efforts through policy frameworks and funding mechanisms. For instance, in South Africa, the City of Cape Town works in conjunction with the National Department of Water and Sanitation to implement integrated water management strategies (Faragher & Carden, 2023). Similarly, in India, the governance of urban water systems in Bengaluru involves a polycentric system that includes national, state, and city levels (Reymond et al., 2020).

At the transnational level, the implementation of NBS is guided by EU directives and international agreements, which provide financing guidance and promote compliance with broader environmental goals. The integration of local government policies with international strategies, such as the EU Biodiversity Strategy 2030, exemplifies this multi-level governance approach (Miroshnyk et al., 2022). In Flanders, Belgium, the governance of NBS projects involves European, regional, provincial, and city levels, highlighting the importance of cohesive and collaborative governance structures (Casiano Flores et al., 2021).

4.4. Management-strategic cycle phases in NBS implementation

The governance of NBS encompasses several key management phases; from goal-setting, analysis, strategy formation, implementation, to strategy monitoring.

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Goal-setting involves defining objectives that align with sustainability and resilience goals, such as improving water quality, preserving green infrastructure, and establishing integrated water services infrastructure (Faragher & Carden, 2023; Gabriel, 2016; Staddon et al., 2017), establishing water resilience goals, and integrating urban water management (Koop et al., 2022; Miroshnyk et al., 2022; Moglia & Cook, 2019), mitigating flood risks, improving social, economic, and ecological conditions, and integrating ecosystem services into urban planning (Blazy et al., 2021; Hohmann et al., 2025; Mottaghi et al., 2020), transforming cities into liveable, resilient sponge cities and integrating sustainable food production systems (Francisco et al., 2023; P. Zhang et al., 2019), integrating BGI and establishing water security and sustainability goals (Quezada et al., 2016; Sadegh Koohestani et al., 2025).

The analysis phase includes assessing environmental impacts, spatial and statistical analysis of urbanization impacts, and evaluating water-related challenges (Hopkins et al., 2018; Miroshnyk et al., 2022), evaluating water demand and supply, and reviewing the effectiveness of NBS (Biswal & Balasubramanian, 2022; Knapik et al., 2024). The analysis phase includes assessing the impact of urbanization on ecosystems, evaluating water quality, pollution sources, and flood risks, and using tools like the Infrastructure Transition Canvas (ITC) to map actors, resources, and coordination tasks (Hohmann et al., 2025; Shilky et al., 2024a; J. Zhang et al., 2022). The analysis phase includes assessing environmental impacts, evaluating water quality, pollution sources, and flood risks, and reviewing the effectiveness of NBS (Soares Dal Poz et al., 2022b; Y. Sun et al., 2020). The analysis phase includes evaluating challenges and barriers, assessing water demand and supply, and reviewing literature to identify societal values (Palmeros Parada et al., 2022; Quezada et al., 2016; Sadegh Koohestani et al., 2025).

Strategy formation involves developing plans that incorporate NBS into broader urban development strategies, such as creating master plans, developing policies for sustainable urban development, and forming new governance models (Casiano Flores et al., 2021; Gabriel, 2016; Staddon et al., 2017). An important strategy is incorporating NBS into broader urban development strategies, designing hybrid systems, and developing integrated management strategies and collaborative governance and partnerships (Knapik et al., 2024; Palermo et al., 2023; Zauscher et al., 2025), designing blue-green solutions and creating collaborative governance structures and partnerships (Hohmann et al., 2025; Knapik et al., 2024; Mottaghi et al., 2020), designing NBS systems, developing governance frameworks, and creating WSUD policies, developing recovery technologies, and designing

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integrated solutions informed by systems thinking (Mguni et al., 2022; Palmeros Parada et al., 2022; Wan Rosely & Voulvoulis, 2023b).

Implementation entails executing NBS projects through collaborative efforts among stakeholders, including policy interventions, public-private partnerships, and upgrading wastewater treatment infrastructure (Gabriel, 2016; Malisa et al., 2019). Implementation entails executing NBS projects through collaborative efforts among stakeholders, including installing green roofs, rain gardens, and permeable pavements, as well as adopting stormwater harvesting and wastewater reuse (Keremane et al., 2017; McClymont et al., 2020), constructing green roofs, urban parks, and permeable pavements, and retrofitting neighborhoods with blue-green solutions (Mottaghi et al., 2020; Shilky et al., 2024), installing green roofs, rain gardens, and permeable pavements, and adopting stormwater harvesting and wastewater reuse (Keremane et al., 2017; McCarton et al., 2022). Implementation entails including pilot projects, constructing SUDS elements like swales and green roofs, and employing participatory approaches (Gimenez-Maranges et al., 2023; Mguni et al., 2022; Wan Rosely & Voulvoulis, 2023b).

Strategy monitoring and adaptive learning involves assessing the effectiveness of NBS projects, evaluating park conditions, and continuous stakeholder engagement (Gabriel, 2016; Malisa et al., 2019). Strategy monitoring involves evaluating system performance, and continuous stakeholder engagement (O'Donnell et al., 2018; Sulieman et al., 2025; Wan Rosely & Voulvoulis, 2023b), evaluating the hydrological effectiveness of NBS, and conducting studies to assess performance, cost-benefit, and environmental impacts (Hohmann et al., 2025; Palermo et al., 2023), inform adaptive management and policy refinement, using evidence from monitoring and evaluation to assess progress and societal impacts (Palmeros Parada et al., 2022; Wan Rosely & Voulvoulis, 2023b).

4.5. Role of co-creation, co-design in NBS governance

Interdisciplinarity (Collaboration of disciplines)

Interdisciplinary collaboration is crucial for effective urban planning and environmental management. Biswal & Balasubramanian (2022) emphasize the importance of co-design involving urban planners, environmental engineers, and managers. Shilky et al. (2024) highlight the involvement of urban planners, landscape architects, ecologists, and other stakeholders to ensure solutions are tailored to local contexts and meet community needs. Hohmann et al. (2025) discuss participatory planning processes involving municipal departments, approval authorities, and citizens. Abd Aziz et al. (2023) emphasize stakeholder participation in planning and decision-making processes for successful BGI implementation. Li

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et al. (2021) and Puppim De Oliveira et al. (2022) underscore the importance of collaboration between various stakeholders for successful NBS implementation. (Wendling et al., 2018) and (Herslund et al., 2018) mention stakeholder participation in the design, development, implementation, and management of NBS. Many studies highlight interdisciplinary collaboration in various domains such as NBS development, sponge city systems, sustainability indicators, decentralized wastewater treatment technologies, integrated urban planning, and water reuse strategies (Francisco et al., 2023; Kılkış et al., 2019, 2023; Langergraber et al., 2020; McCarton et al., 2022; Pearlmutter et al., 2020; Rebelo & Farabegoli, 2025; Ribarova et al., 2024; Soares Dal Poz et al., 2022a; Sulieman et al., 2025; Y. Sun et al., 2020). Additionally, some others emphasize interdisciplinary collaboration in the implementation of BGI, NBS, sustainable urban water systems, and integrated urban water management (Atanasova et al., 2021; Basu & Das, 2021; Bell, 2015; Dobre et al., 2018; Gimenez-Maranges et al., 2020, 2023; Johannessen et al., 2019; Lü Yonglong et al., 2019; Mguni et al., 2022; Palmeros Parada et al., 2022; Perales-Momparler et al., 2017; Pineda-Martos et al., 2024; Quezada et al., 2016; Rodrigues & Antunes, 2021; Sadegh Koohestani et al., 2025; Van Der Meulen et al., 2023; Wan Rosely & Voulvoulis, 2023b; Zevenbergen et al., 2018).

Transdisciplinarity (Co-design)

Transdisciplinary approaches, particularly co-design, are vital for developing innovative and inclusive urban solutions. Malekpour et al. (2021) highlight co-design in the Brabham case, where stakeholders collaboratively developed innovative technical interventions in Perth, Australia. Johannessen & Mostert (2020) emphasize co-design as a collaborative approach involving various stakeholders in urban water governance and learning transitions. Chaffin et al. (2019) describe co-design through the collaborative efforts of stakeholders in planning, designing, and implementing GI projects. Faragher & Carden (2023) and Staddon et al. (2017) mention community engagement and collaborative governance as integral to co-design. Reymond et al. (2020) and Simon (2023) highlight the involvement of stakeholders, including government agencies, private sector service providers, and civil society, in the co-production of strategies and transformations in urban governance. Rogers et al. (2020) highlight co-design in participatory assessment methodology involving local experts and stakeholders. Kopp et al. (2025) and McClymont et al. (2020) discuss the involvement of various stakeholders, including public administration, investors, planners, and the public, in the planning and implementation process, highlighting participatory processes and communication with the public as important tools. Hendricks and Dowtin (2023) and Maher (2020) mention the involvement of urban planners, local authorities, landscape architects,

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and community members in the planning and design process, ensuring effective implementation and maintenance of hybrid Green–Gray systems and blue-green infrastructure. Alexandre (2018) and Shi et al. (2024) describe the involvement of community members, local artists, and residents in the planning and design of green infrastructure projects, enhancing social cohesion and ensuring that projects meet community needs. (Sun et al. (2024) and Moglia and Cook (2019) emphasize participatory processes involving diverse stakeholders, ensuring that solutions are equitable and meet the needs of all stakeholders. Tsatsou et al. (2023) emphasize stakeholder engagement in the design and implementation process.

4.6. Actors driving the shift towards NBS

Various actors contribute to the mainstreaming of NBS.

Governments, international institutions and policy makers

Local government officials, city managers, and representatives are crucial in urban settings and green infrastructure projects, ensuring initiatives are tailored to local needs and effectively implemented (Alexandre, 2018; Gabriel, 2016; Hopkins et al., 2018; Kopp et al., 2025; Mguni et al., 2022). Provincial and regional governments, such as Antwerp, demonstrate the importance of multi-level governance in NBS projects (Casiano Flores et al., 2021). National governments, for example the Chinese government, exemplify the significance of multi-level governance through the involvement of multiple governing institutions (Chan et al., 2018; Shi et al., 2024). International organizations like the OECD, UN, WHO, FAO, and the European Commission also play significant roles in promoting NBS globally (Koop et al., 2022; Li et al., 2021).

Academic and research institutions

Researchers, academics, and universities drive NBS initiatives and contribute to their successful implementation through rigorous research and innovation. Collaborative research and development projects provide the necessary knowledge and expertise to advance NBS (Johannessen & Mostert, 2020; Lü Yonglong et al., 2019; McClymont et al., 2020; Palermo et al., 2023; Pineda-Martos et al., 2024).

Community, civil society, and NGOs

Community groups, civil society organizations, and NGOs are vital for the implementation and maintenance of NBS projects, ensuring that solutions are community-driven and address local needs. They collaborate with local governments and researchers to promote sustainable practices and enhance community engagement (Alexandre, 2018; Gabriel, 2016; Miroshnyk et al., 2022;

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Puppim De Oliveira et al., 2022). Networks of stormwater professionals, including government agencies, NGOs, and academic institutions, significantly contribute to green infrastructure projects by sharing knowledge and best practices (Chaffin et al., 2019).

Utilities, infrastructure, and specialized agencies

Water utilities and sewer authorities play significant roles in green infrastructure projects and urban water management, contributing to the planning, design, and implementation of sustainable water systems. Their involvement ensures that water systems are efficient and resilient (Chaffin et al., 2019; Hopkins et al., 2018; Rogers et al., 2020). Specialized agencies and departments, such as the Ministry of Water Resources and the Ministry of Environment in China, exemplify the importance of multi-level governance in NBS projects. They involve multiple governing institutions to ensure comprehensive management and address urbanization impacts (Chan et al., 2018; Francisco et al., 2023; Soares Dal Poz et al., 2022).

Urban planners and private sector

Urban planners, city planners, landscape architects, environmental engineers, private companies, and consultants drive NBS initiatives by integrating sustainable practices into urban development plans and collaborating with other stakeholders. Their expertise ensures that projects are both functional and aesthetically pleasing, and they provide innovative solutions and expertise for effective planning and execution (Biswal & Balasubramanian, 2022; Hendricks & Dowtin, 2023; Knapik et al., 2024; Martín Muñoz et al., 2024; Mguni et al., 2022; Palermo et al., 2023).

4.7. Barriers to NBS implementation

From a governance perspective, the fragmentation of institutional structures is one of the most frequently cited barriers to the mainstreaming of NBS. Sectoral silos, narrowly defined mandates, and competing priorities across agencies limit cooperation and trust among stakeholders (Malekpour et al., 2021; Casiano Flores et al., 2021). Responsibilities are often divided between different government levels without clear coordination mechanisms, resulting in duplication, inefficiencies, or gaps in management (Langergraber et al., 2020). Where collaboration does occur, it is typically temporary, linked to externally funded projects, and rarely institutionalised in statutory planning frameworks, which undermines continuity and scaling (IPBES, 2024; Rogers et al., 2020). These entrenched structures reinforce conventional grey practices and make it difficult to introduce governance innovations (O'Donnell et al., 2018; Kopp et al., 2025).

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Regulatory and policy gaps further complicate adoption. The lack of harmonised standards for green and hybrid infrastructure generates uncertainty in design and procurement processes, discouraging municipalities from committing to large-scale deployment (Shilky et al., 2024a). In many contexts, water reuse and NBS remain outside formal regulations, leaving projects vulnerable to legal challenges or stalled approvals (Casiano Flores et al., 2021). Moreover, existing governance frameworks often fail to incorporate sustainability criteria or to align urban water management with broader planning goals, slowing institutional change (Ribarova et al., 2024).

Financial barriers are also central. While NBS often demonstrate long-term cost-effectiveness, they are associated with higher upfront investment and maintenance uncertainty, making them less attractive within short-term municipal budgeting cycles (Biswal & Balasubramanian, 2022; Gabriel, 2016). Limited funding streams, fragmented responsibilities for financing across agencies, and the absence of standardized frameworks for integrating ecosystem service valuation all restrict the ability to mobilize resources (McClymont et al., 2020; Sun et al., 2024). Even when external support is available, the lack of long-term financial planning and budgeting often undermines sustainability (Martín Muñoz et al., 2024; Hopkins et al., 2018).

Finally, capacity and knowledge gaps further obstruct the mainstreaming of NBS. Municipal staff often lack technical expertise in NBS design and management, while entrenched engineering paradigms privilege conventional grey solutions (Tsatsou et al., 2023; Herslund et al., 2018). Weak communication across institutions, reluctance to change practices, and low public awareness reduce acceptance and create resistance to innovation (Wendling et al., 2018; Malisa et al., 2019). Issues of ownership and access rights to new water resources, combined with mixed perceptions about maintenance and the absence of reliable performance data, add additional uncertainty (Keremane et al., 2017; Adem Esmail & Suleiman, 2020; Knapik et al., 2024).

4.8. **Enablers for NBS implementation**

Mirroring the types of barriers, various enablers are mentioned:

Governance and policy support

Much of the literature stresses that governance support for NBS emerges at the interface of top-down policies and bottom-up demand. Policies that enable transparency, experimentation and cross-sector collaboration are often cited as crucial (Malekpour et al., 2021), their effectiveness depends on local uptake and community engagement. Research shows the potential of public–private partnerships and volunteer initiatives (Gabriel, 2016), but their long-term

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institutionalisation remains unclear. Studies on integration of water management and urban planning highlight promising strategies and instruments (Casiano Flores et al., 2021; Faragher & Carden, 2023; Staddon et al., 2017), but implementation often stalls due to fragmented responsibilities and weak legal frameworks (Ribarova et al., 2024).

Collaboration and stakeholder engagement

Collaboration indicators from trust networks (Chaffin et al., 2019a) to participatory planning processes (Malisa et al., 2019) are widely used to highlight the social processes behind successful NBS. These contributions stress that technical outcomes depend on stakeholder trust, communication and capacity-building (Adem Esmail & Suleiman, 2020; Wendling et al., 2018). Most of the literature focuses on short-term engagement during project development. Less is known about how collaborative arrangements persist after projects end, or how informal networks interact with formal governance structures.

Technological and innovative approaches

Studies highlight the role of technologies such as membrane bioreactors or decision support tools (DSTs) in increasing efficiency and transparency in water management (Malisa et al., 2019; Biswal & Balasubramanian, 2022). These contributions have advanced debates by showing how technical innovation can open up new governance possibilities, for example by making ecosystem services quantifiable and comparable (Adem Esmail & Suleiman, 2020). However, research often treats technologies as neutral tools, underplaying the political choices embedded in their design and use.

Urban planning and infrastructure

Indicators such as integrated indices of green infrastructure (Miroshnyk et al., 2022) or urban sprawl matrices (Sahana et al., 2018) show how NBS performance is linked to spatial development. The academic debate recognises that NBS cannot be mainstreamed without addressing broader land-use dynamics and cross-departmental planning (Zhang et al., 2022). Most studies stop at diagnostic tools. There is limited analysis of how planning frameworks operationalise these indices in practice, or how spatial indicators can shift actual resource allocation and regulatory enforcement.

Education and social learning

Social learning is presented as a governance enabler, increasing adaptive capacity and improving systemic understanding (Johannessen & Mostert, 2020; O'Donnell

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et al., 2018). Public information campaigns are also framed as prerequisites for acceptance and long-term maintenance (Gimenez-Maranges et al., 2023). The literature thus contributes by linking governance performance with the capacity of actors to learn and adapt. Empirical evidence remains scattered: how learning processes are institutionalised, scaled and measured is not well documented.

Financial and regulatory support

Indicators of financial support range from avoided costs and life-cycle analyses (Biswal & Balasubramanian, 2022; McClymont et al., 2020) to external funding streams (Li et al., 2021; Puppim de Oliveira et al., 2022). This literature contributes to the academic debate by demonstrating the mismatch between short-term cost accounting and long-term NBS benefits. It also highlights the fragility of relying on project-based or external funding.

Environmental and sustainability initiatives

Research on environmental performance from runoff reduction (Palermo et al., 2023) to ecological compensation (Shi et al., 2024) provides the strongest evidence base for NBS effectiveness. These indicators show the ecological rationale for adoption and have informed planning debates. However, their contribution to governance debates is weaker: while they quantify benefits, they rarely explore how such data influence political decision-making, planning priorities, or regulatory reforms.

Box 2: São Paulo, Brazil (Soares et al., 2022)
The São Paulo Urban Living Laboratory focused on the Food, Energy, and Water Nexus to develop sustainable systems at the border of the Atlantic Forest in southeast Brazil. The technical interventions included the use of system dynamics modelling and the Delphi method to analyse and model complex food production systems. The organizational transformation involved creating a network of stakeholders, including regulatory and environmental monitoring agencies, municipalities, rural producer cooperatives, policy makers, third sector organizations, and technical production support bodies. This network formed situation arenas where stakeholders collectively defined sustainability indicators and developed decision-making tools. The São Paulo ULL facilitated the formation of these networks and provided a platform for stakeholders to collaborate, share knowledge, and make collective decisions. The governance framework was based on three dimensions: Physical and Material Conditions, Attributes of Communities, and Rules-in-Use, which guided the assessment of sustainability levels and the implementation of innovative practices.

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5 INDICATORS AND METRICS FOR MEASURING WATER NBS

A wide set of indicators across environmental, social, economic and governance scales are mentioned that demonstrate the multifaceted benefits of NBS.

Environmental indicators

Environmental indicators are widely used to evaluate the ecological performance of NBS. Measures such as urban greening levels and water quality (Malekpour et al., 2021; Tsatsou et al., 2023) help track the direct impact of interventions on urban ecosystems. More complex metrics, like resilience indicators framed through triple-loop learning (Johannessen & Mostert, 2020), capture adaptive capacity over time. Indicators of biodiversity and park ecosystem health (Miroshnyk et al., 2022) or volumes of stormwater managed (Hopkins et al., 2018) translate ecological functions into quantifiable services, which can support decision-making and funding allocation. Performance measures such as pollutant removal efficiency, infiltration rates, and peak flow attenuation (Biswal & Balasubramanian, 2022; Palermo et al., 2023) provide technical validation of NBS as substitutes or complements to grey infrastructure. However, studies note persistent challenges in designing meaningful monitoring programmes and selecting robust indicators, particularly for long-term benefits and emerging pollutants (Zhang et al., 2022; Ribarova et al., 2024).

Social indicators

Social indicators contextualise NBS beyond ecological performance, linking them to community well-being, amenity and equity (Malekpour et al., 2021; Johannessen & Mostert, 2020). They have been applied to measure park usage, satisfaction, and quality of life improvements (Gabriel, 2016; Biswal & Balasubramanian, 2022), as well as trust, social cohesion, and interaction with blue–green spaces (O'Donnell et al., 2018; Adams et al., 2024). These measures demonstrate that NBS can generate co-benefits that strengthen public support and legitimacy, but they also reveal inequities in access (Alexandre, 2018; Mguni et al., 2022). Social indicators also capture participation and engagement, e.g. stakeholder involvement in urban agriculture or water reuse initiatives (Simon, 2023; Malisa et al., 2019), which are crucial for long-term governance. Their added value lies in showing how NBS affect everyday life and in revealing barriers related to equity and acceptance.

Economic indicators

Economic indicators demonstrate the cost-effectiveness and financial viability of NBS compared to conventional infrastructure. Analyses of avoided costs, cost–benefit ratios, and life-cycle costing (Malekpour et al., 2021; McClymont et al., 2020; Kopp et al., 2025) provide crucial evidence for municipal investment decisions.

Indicators such as proportion of funds allocated to green infrastructure (Hopkins et al., 2018) or employment opportunities created (Blazy et al., 2021) link NBS to fiscal priorities and socio-economic development. Some studies use water and carbon footprints (Francisco et al., 2023) or resource recovery measures (Langergraber et al., 2020) to embed NBS into circular economy models, while others estimate the cost of inaction to stress long-term benefits (Van Leeuwen et al., 2019). The added value of economic indicators is that they translate ecological and social functions into financial arguments that resonate with decision-makers.

Governance indicators

Governance indicators assess how institutional and policy frameworks enable or constrain NBS. Measures of collaboration effectiveness, policy integration, and coordination across agencies (Johannessen & Mostert, 2020; Reymond et al., 2020) have been applied to evaluate whether multi-sector governance structures function effectively. Network analysis (e.g. size, frequency of collaboration, centrality) provides insights into actor relationships and governance capacity (Chaffin et al., 2019a). Other studies focus on policy compliance, regulatory tools, and effectiveness of governance arrangements (Koop & Van Leeuwen, 2017; Knapik et al., 2024), which are essential for scaling NBS. Governance indicators add value by making visible the institutional conditions behind technical performance, highlighting whether enabling environments are in place for mainstreaming.

6 DATABASES ON IMPLEMENTED URBAN NBS CASES

Apart from scholarly literature, existing databases can provide an important source of information about the running of NBS and the approaches to them.

Urban Water Atlas (https://www.urbanwateratlas.com/), Urban Nature Atlas (https://una.city/), and Urban Governance Atlas (https://interlace-hub.com/urban-governance-atlas) provide a wealth of information on urban sustainability and NBS, with some focussing specifically on water and others containing a significant amount of information on water based cases. These databases collectively cover a wide range of topics, including water management, green infrastructure, biodiversity, and urban governance. Their perspective is holistic, emphasizing the interconnectedness of environmental, social, and economic factors in urban planning. By compiling case studies, policy instruments, and innovative practices from various cities, these databases contribute significantly to the existing body of knowledge. They offer valuable insights into successful strategies and challenges,

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enabling researchers, policymakers, and practitioners to learn from real-world examples and apply best practices in their own contexts.

The Urban Water Atlas is a comprehensive resource that illustrates the role of water in urban settings, particularly in European cities. It provides detailed fact sheets on water management practices in over 40 cities and regions, including some overseas examples. The Atlas aims to raise awareness about water usage, promote efficient and sustainable water management practices, and encourage citizen involvement. It includes information on cities' "Urban Water Footprint," which measures domestic water use and the water used in producing agricultural and industrial products consumed by the city. The Atlas also highlights innovative solutions and best practices for urban water management, aiming to change perceptions of water as an infinite resource and promote conservation.

The Urban Governance Atlas is an interactive online database developed as part of the INTERLACE project. Launched in May 2023, it showcases over 250 policy instruments from 41 countries that support NBS and ecosystem restoration. The Atlas categorizes these instruments into legislative, regulatory, strategic, economic, fiscal, cooperative, and knowledge-based tools. It provides detailed descriptions of each policy instrument, including their design, implementation, governance approaches, and lessons learned. The Atlas is designed to help policymakers, urban planners, researchers, and civil society organizations explore successful governance strategies and enhance urban resilience, biodiversity, and social inclusion. The content is available in multiple languages, making it accessible to a global audience.

The Urban Nature Atlas was developed in 2017 as part of the Horizon 2020-funded Naturvation project (NATure-based URban innoVATION), has now been integrated into the NATURGO project. It is the largest database, featuring over 1000 cases from 100 European cities. The Urban Nature Atlas includes a wide range of projects, such as green buildings, parks, community gardens, and river management initiatives. Each entry in the database provides detailed information on the project's goals, implementation activities, governance features, financing, innovations, and benefits. One of the key strengths of the Urban Nature Atlas is its global reach and thoroughly researched description of cases. While it initially focused on European cities, the Atlas has expanded to include projects from other regions, such as Asia, supported by the Asia-Europe Foundation. Examples of projects in the Urban Nature Atlas related to water governance and urban water NBS include rainwater harvesting systems, constructed wetlands for stormwater management, and river restoration projects. These initiatives not only address water management

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challenges but also provide additional benefits such as improved water quality, enhanced biodiversity, and recreational opportunities for urban residents.

The Urban Nature Atlas includes a significant number of cases focused on water management, which can be filtered according to four specific water-related challenges. Specifically, there are 226 related to flood protection, 326 related to stormwater and rainfall management and storage, 190 related to improvements to water quality and 4 about water security. Water NBS related case studies were grouped, and the analysis was organised by systematically approaching to ensure comprehensive understanding and effective comparison. Case studies were grouped based on various criteria such as geographical location, type of water-related challenge (e.g., water scarcity, pollution, flooding), and the specific NBS implemented (e.g., rainwater harvesting, wetland restoration, green infrastructure). Once grouped, the analysis was organized by examining key aspects such as the objectives of each project, the methods used, the outcomes achieved, and the lessons learned. This structured approach allowed for identifying common patterns, successful strategies, and areas for improvement, facilitating the development of best practices and informing future projects.

Based on the environmental, social, economic, governance, technical feasibility criteria, below we present 20 worldwide projects related to urban water NBS:

The Rain Garden project along October 28th Street in Greece aimed to address stormwater management issues while enhancing urban greenery. By installing rain gardens, the project captured and filtered stormwater, effectively reducing flooding and improving water quality. This initiative demonstrated that rain gardens not only manage stormwater efficiently but also contribute to the aesthetic enhancement of urban spaces, making them more attractive and environmentally friendly. In France, the Stormwater Retention Basins project focused on preserving coastal water quality and reducing flooding. The construction of stormwater retention basins played a crucial role in managing urban stormwater and protecting coastal areas from pollution. The project underscored the importance of retention basins in urban water management, highlighting their effectiveness in mitigating flood risks and maintaining the health of coastal ecosystems. The Aarhus River Project in Denmark aimed to restore the Aarhus River to improve water quality and urban biodiversity. The project involved river restoration techniques such as removing pipes and re-naturalizing the riverbed. As a result, water quality was significantly enhanced, and biodiversity increased along the river. This project illustrated the substantial benefits of river restoration for urban ecosystems, showcasing how such initiatives can revitalize natural habitats and improve environmental health. The Adyváros Lake Rehabilitation project in Hungary addressed water management issues while

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enhancing recreational spaces. Through lake rehabilitation and the creation of recreational areas, the project improved water management and provided new opportunities for community recreation. This initiative demonstrated that combining water management with recreational development can foster community engagement and support the success of urban environmental projects. In Norway, the Alna Environmental Park project aimed to improve urban water management and biodiversity by daylighting previously piped rivers and creating environmental parks. The outcomes included better water management and increased urban biodiversity, highlighting how daylighting rivers can transform urban areas and enhance ecological health. This project showcased the potential of environmental parks to serve as vital green spaces within urban settings. The Green Promenade project in Cagliari, Italy, sought to combat soil sealing and improve urban biodiversity. By creating green promenades and planting native species, the project enhanced urban biodiversity and reduced soil sealing. This initiative demonstrated the effectiveness of green promenades in improving urban ecosystems, providing valuable green spaces that support biodiversity and contribute to the overall health of the urban environment. The Diakonissen Klinik Roof Garden project in Germany aimed to enhance urban green spaces and improve air quality. By installing a roof garden with intensive greening, the project achieved improved air quality and increased urban greenery. This initiative highlighted the benefits of roof gardens in urban settings, showing how they can effectively enhance green spaces and contribute to better air quality. The Urban Forest of Mount Urpinu project in Italy focused on restoring biodiversity and improving urban green spaces. By planting 6400 new trees and creating urban forests, the project successfully restored biodiversity and enhanced urban green spaces. This initiative underscored the significant benefits of urban forests for biodiversity and urban environments, demonstrating their role in creating healthier and more sustainable cities. In France, the Management Strategy for Abandoned Areas project aimed to valorize abandoned urban areas and improve their management. Through large census projects and providing management guidance, the project improved the management of abandoned areas and enhanced urban spaces. This initiative showcased the transformative potential of effective management strategies for abandoned urban areas, highlighting their ability to revitalize neglected spaces and integrate them into the urban fabric. The Afforestation project in Aarhus, Denmark, aimed to protect groundwater and enhance urban green spaces by planting woods in vulnerable areas and creating urban forests. The project resulted in protected groundwater and improved urban green spaces, demonstrating that afforestation can effectively safeguard water resources and enhance urban environments. This initiative highlighted the importance of afforestation in urban water management and

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environmental conservation. The Cheonggyecheon Stream Restoration in Seoul, South Korea, transformed a covered stream into a vibrant public space, enhancing water quality and flood management. Singapore's ABC Waters Programme integrates blue-green infrastructure to improve water quality and manage stormwater. The High Line in New York City, USA, repurposes an elevated rail line into a park with sustainable water practices. Melbourne's Urban Forest Strategy in Australia increases tree canopy cover to manage stormwater and reduce urban heat. The Davis Pond Freshwater Diversion Project in Louisiana, USA, reintroduces fresh water to the Barataria estuary, aiding marsh restoration. Quito's Water Management Initiatives in Ecuador focus on improving water quality and stormwater management. The Kimbe Bay Marine Protected Area in Papua New Guinea protects biodiversity and enhances water quality. Portland's Green Streets Program in the USA uses green infrastructure to manage stormwater and reduce flooding. Bogotá's River Restoration Projects in Colombia aim to restore urban rivers and improve water quality. Lastly, Cape Town's Water Conservation and Demand Management Strategy in South Africa adopts a comprehensive approach to managing water resources and reducing consumption.

7 POLICY REPORTS ON URBAN WATER RELATED NBS

In the past years, many reports have been compiled regarding the significance and implementation of NBS. Many of them are relevant to the project NATURGO and urban water-related NBS, providing valuable insights, practical guidance, best practices and evidence-based strategies for integrating NBS into urban planning. These reports help policymakers, urban planners, and other stakeholders understand the benefits of NBS in improving water quality, mitigating flooding, and enhancing resilience to droughts. Furthermore, they emphasize the importance of strategic planning, investment, and public awareness in fostering sustainable development and creating resilient urban environments.

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Table **1**: Reports on urban water related NBS. (***) - reports with critical insights or information directly related to the core objectives of the project; (**) - reports with useful information and contribute to the understanding of the project.

Organisation	Title (year)	What it says	Governance relevance	What is missing
IDB	Increasing Infrastructure Resilience with NBS (2020)	12-step process for including NBS in infrastructure projects.	Shows how to make NBS "bankable" for engineers and financiers.	Weak on long-term maintenance and institutional reforms.
SEI	Addressing Scale in NBS (2022)	Framework for scaling NBS beyond pilots.	Highlights enabling and blocking conditions for scaling.	Conceptual; lacks examples of concrete governance reforms.
IUCN	Global Standard for NBS (2020); ENACT Roadmap (2024)	Criteria and roadmap for designing and evaluating NBS.	Emphasises participation, safeguards, equity.	High-level; little practical guidance for municipalities/utilities.
OECD	Scaling up NBS to tackle water risks (2021); Municipal reforms in Hungary (2023)	Shows how national/local policies can support NBS.	Identifies planning and fiscal levers.	Focus on Europe; little detail on implementation in diverse contexts.
EEA	Water management (2017); NBS in Europe (2021); Scaling NBS (2023)	Analyses how NBS can be integrated in EU policy and practice.	Links NBS to EU policy, funding, and planning frameworks.	EU-centric; limited equity and global relevance.
UN	Nature-Based Solutions for Water (2018)	Advocates for NBS as part of SDGs.	Positions NBS in global political agendas.	Broad and general; little operational detail.
UN Environment & IUCN	Primer on NBS for Water Management (2018)	Outlines benefits and strategies for NBS in water.	Stresses role of governance in adoption.	Generic; lacks tested governance pathways.
World Bank	Implementing NBS for Flood Protection	Provides design and implementation	Shows how NBS can complement	Technical focus; limited attention to governance/institutions.

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	(2017); Integrating Green & Gray (2019); Catalogue of NBS for Urban Resilience (2021)	guidance for engineers and planners.	conventional infrastructure.	
European Commission	Cost-benefit assessment for NBS (2020); Harnessing collaboration (2023); Bridging continents (2024)	Focuses on economics, collaboration, and knowledge transfer.	Highlights participation and financing mechanisms.	Few examples of legal, regulatory, or institutional reforms.
ICLEI	Taking NBS up the policy ladder (2022)	Moves from research to policy action.	Stresses participatory and co-governance approaches.	Principle-oriented; limited concrete tools for enforcement.
ERDC	Community Engagement Framework for NBS (2022)	Shows good practices for stakeholder engagement.	Provides practical engagement guidance.	Does not link participation to formal policy outcomes.
ADB	Governance approach to water PPPs (2022a); NBS for climate adaptation & risk management (2022b)	Explores PPPs and NBS case studies in Asia.	Shows how private actors can be part of governance.	Regional focus; less transferability elsewhere.
British Academy	Valuing Inclusion and Diversity (2021)	Highlights links between NBS, inclusion, and uncertainty.	Introduces governance principles for inclusion.	Conceptual, not operational.
Wageningen UR	Imagining a nature-based future for Europe 2120 (2023)	Long-term scenarios and visions for NBS.	Raises foresight and planning questions.	Scenario-based; no direct governance tools.
Eawag, UC Berkeley, BlueTech	Mainstreaming Decentralized UWM (2024)	Focuses on decentralised water solutions.	Links NBS to governance of decentralised systems.	Limited to case studies; little institutional integration.

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Interreg Europe	Water Resilience (2025); Climate adaptation: wetlands, peatlands & grasslands (2023); Green & Blue Infrastructure (2023)	Provides regional case studies and recommendations.	Useful for local/regional cooperation on NBS.	EU-focused; less applicable globally.
IISD	Unpacking Methods for Integrated Assessments of NBS (2025)	Guidelines for integrated assessments and valuation.	Connects governance with decision-support methods.	Early-stage; not tested in practice.

Common gaps across reports:

- Reports point to the need for enabling policies, but rarely explain how institutions or rules changed (e.g. revised mandates, new laws, regulatory enforcement).
- Few examples of zoning codes, tariffs, or procurement reforms that make NBS mandatory rather than optional.
- Reports discuss cost–benefit but ignore long-term financial rules, budgeting for maintenance, or blended finance schemes.
- Scaling is a common theme, but concrete governance mechanisms (subsidies, standards, cross-agency mandates) are not addressed.
- Reports stress their importance but do not show governance tools that guarantee equitable outcomes or long-term involvement.
- Indicators are mentioned, but they are not tied to decision rules like funding allocation, compliance, or permit conditions.

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8 KNOWLEDGE GAPS

There is a wealth of publications on the topic of NBS in urban contexts, both peer-reviewed and grey literature. The governance of NBS and the question of how NBS are governed across scales is a common element of these studies both implicitly and explicitly. It is recognised that NBS are needed but often not or poorly implemented, pointing to the failure of governance structures and practices in accomplishing the goal. Implementation of NBS requires changes across different scales and dimensions, which makes the introduction, acceptance and maintenance of NBS an instance of transition or transformation, with the following identified knowledge gaps.

While multiple benefits of the NBS in urban areas have been extensively documented (e.g. Seddon et al., 2020; Smith et al., 2017; Chausson et al., 2020; Raymond et al., 2017; Liquete et al., 2016; Markanday et al., 2019; IUCN, 2016; van den Bosch and Sang, 2017), there is little detailed knowledge of the **trade-offs (including spillover effects)** of actions that aim to introduce NBS, particularly with regard to their unintended consequences. These include potential negative socio-ecological consequences such as high maintenance costs, low acceptance or unintended social impacts like gentrification. Thus, an understanding is missing of the extent to which NBS adoption may not be a straightforward governance objective to pursue for the decision-makers.

The above mentioned gap in understanding NBS trade-offs and spillover effects is fundamentally driven by a deficit of **long-term empirical evidence**. Currently, the advocacy for NBS often relies on anecdotal case studies or short-term projections, lacking the quantitative, comparative data needed for rigorous assessment. Insufficient empirical evidence is available regarding the long-term performance, maintenance costs, and evolving benefits of multifunctional and integrated projects. Rigorous analyses comparing the full costs and benefits (including social and ecological dimensions) of NBS against conventional "grey" infrastructure alternatives are difficult and understandably scarce, while they might be key for the decision-making processes.

A critical gap exists regarding specific, **on-the-ground mechanisms within governance systems that systematically hinder implementation** of NBS. While high-level barriers, present a burden to a coordinated implementation, there is a lack of analysis of how these barriers actually operate in practice and what leverage. An insight is missing into the micromechanisms of failure, such as the (reasons behind) specific siloed decisions, power dynamics, budget cycles, and points in the decision-making pipeline where NBS projects are derailed.

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For example, it is known that institutional fragmentation impedes coordination (Tsatsou et al., 2023; Shilky et al., 2023; Kopp et al., 2025). An example is the division of water management responsibilities into a public company controlling drinking water, a (public) company managing storm water drainage and wastewater treatment but not within the same departments, and a third department managing the reuse of treated water). However, we do not understand the exact circumstances (such as a specific veto during a planning committee, a conflicting departmental performance metric, or a legal interpretation that favors grey infrastructure...) that lead to non-implementation of NBS. Such lack of granularity makes it difficult to move from generic awareness of barriers to actionable recommendations, or the ability to point to specific levers, which would allow policymakers to design effective interventions to mainstream NBS. Closing this gap requires in-depth, qualitative case study research that focusses on decision-making processes that document the precise institutional, relational, and material factors that shape outcomes in specific contexts.

While a strong consensus exists in the literature that participatory processes form an integral part of the implementation of long-term NBS because they have the ability to create community ownership of NBS, overcome conflicting values, and ensure equity in decision-making (Koohestani et al., 2025; Malekpour et al., 2021), the **forms of effective participation, the barriers to such participation and the methods of integration of diverse forms of knowledge** (local, experts…) are not mapped or sufficiently discussed. This knowledge and practice gap leaves decision-makers with a mandate to participate but without the practical knowledge to do so in ways that genuinely resonate with stakeholders. This may results in tokenistic consultations, lack of consultations or consultations that fail to build community ownership or ensure equitable outcomes, ultimately undermining the long-term success of NBS projects. To address this, research would move beyond advocating for participation to critically evaluate participatory methods through comparative case studies. This will generate practical frameworks and decision-support tools that guide the design, execution, and integration of legitimate participatory processes in urban NBS governance.

Finally, the literature on NBS is characterized by a **significant geographical bias** towards Western and Northern Europe (e.g. Germany, the Netherlands, the UK, and Scandinavian countries) as well as rapidly urbanising Asian contexts such as China, with a marked emphasis on large metropolitan and coastal cities where flooding, stormwater management, and space constraints are most pressing (Kabisch et al., 2016; Davies & Lafortezza, 2019; Tsatsou et al., 2023). As such, the literature inadequately captures the influence of unique planning traditions,

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institutional path-dependencies, and cultural values found in under-studied regions. For researchers, this gap constrains the generalizability of findings, potentially leading to theories of NBS governance that are context-specific but mistakenly assumed to be universal. For practitioners in under-represented contexts, this gap limits the availability of relevant case studies, making it difficult for them to find relatable examples and transferable models. Addressing this gap requires exploring case study research from a more diverse array of geographic, economic, and cultural contexts to build a robust, comparative knowledge base that can distinguish between universal governance principles and context-dependent adaptations.

NATURGO can move the field forward by addressing several additional gaps. There is a need to study how **cross-sectoral governance mechanisms** can be institutionalised beyond project cycles. Comparative analysis of cities that created permanent NBS units or interdepartmental bodies would yield actionable insights. More work is needed on **financing models** that integrate multi-benefit valuation. Developing and testing blended finance mechanisms, combining public investment, green bonds, and payments for ecosystem services, could demonstrate pathways to overcome financial barriers (Langergraber et al., 2020). Research should focus on **standards, procurement and regulatory alignment**, producing ready-to-use templates for municipal engineers and planners. Likewise, there is a gap in designing governance arrangements for long-term operation and maintenance, which is critical for sustaining benefits. Finally, the social and political dimensions of NBS require deeper investigation. Equity, legitimacy, and distributional effects are rarely analysed in detail, they strongly shape political support and community acceptance (IPBES, 2024). **Monitoring and maintenance** remain fragmented, with limited data on how different systems, from wetlands to hybrid green–grey infrastructure, perform over decades and under changing conditions (Miroshnyk et al., 2022; Tsatsou et al., 2023). The absence of standardized frameworks and indicators exacerbates this gap, as cities struggle to compare outcomes and embed lessons into statutory planning and procurement (Knapik et al., 2024; Hohmann et al., 2025). Without clear standards, monitoring protocols, and maintenance responsibilities, scaling up remains risky and inconsistent. Moreover, **equity and climate resilience** are underexplored in practice. While research points to the importance of distributional justice, social acceptance and community participation (Johannessen & Mostert, 2020; Sulieman et al., 2025), few governance models systematically integrate these dimensions into water planning. Similarly, although NBS are widely recognised as tools for climate adaptation, translating this potential into operational governance frameworks and investment pathways is still limited (Hopkins et al., 2018; Wan Rosely & Voulvoulis, 2023).

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9 CONCLUSION

The literature review provides a robust foundation for designing WP3 by offering insights into effective governance frameworks, strategic planning, and stakeholder engagement necessary for integrating NBS into urban water management. It emphasizes the importance of multi-level governance, cross-sectoral coordination, and inclusive stakeholder engagement, which are crucial for establishing governance baselines and co-creating transition pathways, as well as the need for adaptive management and continuous monitoring, ensuring that strategies developed are resilient and contextually relevant. The literature identifies barriers to NBS implementation that can be tested in real-world cases and knowledge gaps that could be addressed in the NATURGO project.

NATURGO's approach emphasizes effective stakeholder engagement, including active community participation, which is essential for the successful implementation and ongoing maintenance of NBS. By leveraging innovative tools like InflowGo, NATURGO enhances planning and decision-making processes, making them more inclusive and data-driven. Continuous monitoring and adaptive management practices are fundamental to ensuring the long-term success and resilience of NBS projects. Furthermore, NATURGO fosters collaboration and knowledge sharing among international partners, providing valuable insights and best practices that can be tailored to local contexts. These contributions will guide WP3 in crafting comprehensive, sustainable, and resilient urban water governance strategies, ultimately leading to more effective and impactful NBS implementations.

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ANNEX 1

ANNEX 2

ANNEX 3

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