Nature's integration in cities' hydrologies, ecologies and societies

# D4.2 Policy Gaps and Opportunities for the management of urban water SETS

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# Summary


The increasing frequency of extreme weather events due to climate change has highlighted the limitations of traditional gray infrastructure in urban stormwater management. Recurring combined sewer overflow events (CSO) pose significant environmental and public health risks. Nature-Based Solutions (NBS) have emerged as sustainable alternatives, leveraging natural processes to manage stormwater, enhance urban resilience, and provide multiple co-benefits. However, the successful implementation of NBS requires more than technical solutions; it necessitates supportive governance structures and policy frameworks.

This deliverable D4.2 examines the management of urban water systems in the five NICHES cities – Rotterdam, Barcelona, Berlin, Sheffield, and Boston – and assesses how NBS are implemented and embedded in urban policy and planning. It is designed to build a critical basis for T4.3 (co-defining transition pathways) by identifying approaches for restorative NBS implementation within socio-ecological-technological systems. For each city, relevant policy frameworks, government instruments, institutional structures and processes, good practice examples, as well as barriers and enablers have been studied, to define key opportunities and challenges crucial for the introduction of NBS to urban stormwater management.

The research is based on a social-ecological-technical systems (SETS) approach through the integration of innovative ideas for water management in cities with the aim of increasing the resilience and sustainability of urban waterscapes and aquatic biodiversity. By bridging various sectors of urban planning and governance, this approach helps better understand and introduce multiple dimensions of NBS. The comparative analysis of the governance and policy frameworks of five cities reveals a diverse range of enabling and hampering conditions for NBS implementation and CSO mitigation and illustrates the complexities connected to it. While some cities excel in fostering collaborative governance and providing supportive frameworks, others face significant challenges related to institutional fragmentation, data availability, and stakeholder engagement. Collaborative governance, citizen engagement, and innovative tools emerge as critical enablers, while institutional fragmentation, policy gaps, and competing priorities pose significant challenges. Addressing these barriers will require integrated approaches, robust data systems, and inclusive engagement strategies to unlock the full potential of NBS in urban water management.

# List of abbreviations

| | |
|---|---|
| **AMB** | Àrea Metropolitana de Barcelona |
| **BCASA** | Barcelona Cicle de l'Aigua |
| **BerlWG** | Berlin Water Act |
| **BWSC** | Boston Water and Sewer Commission |
| **BWB** | Berliner Wasserbetriebe |
| **CSO** | Combined Sewer Overflow |
| **CSSs** | Combined Sewer Systems |
| **CWA** | National Clean Water Act, Boston |
| **DWGT** | Diagnostic Water Governance Tool |
| **EA** | Environment Agency, Sheffield |
| **EPA** | U.S. Environmental Protection Agency |
| **ESS** | Eco-System Services |
| **KWB** | Kompetenzzentrum Wasser Berlin |
| **MWRA** | Massachusetts Water Resources Authority |
| **NBS** | Nature-Based Solutions |
| **NGOs** | Non-Governmental Organisations |
| **OGI** | Office of Green Infrastructure, Boston |
| **PDU** | Metropolitan Urban Master Plan, Barcelona |
| **PECIA** | Strategic Plan for the Integrated Water Cycle of the Barcelona Metropolitan Area 2023 |
| **PDISBA** | Integral Master Plan of Sanitation of Barcelona |
| **PLARHAB** | Technical Plan for the Use of Alternative Water Resources (2020) |
| **RCI** | Rotterdam Climate Initiative |
| **SETS** | Social-Ecological-Technological- (Systems) |
| **SUDS** | Sustainable Drainage Systems |
| **TMDL** | Total Maximum Daily Load |
| **UK** | United Kingdom |
| **VBOR** | Rotterdam Subsurface Management Regulation |
| **WHG** | Wasserhaushaltsgesetz (Germany's federal water law) |
| **WWTP** | Wastewater Treatment Plants |

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# 1 Introduction

The increasing frequency of extreme weather events due to climate change has highlighted the limitations of traditional gray infrastructure in urban stormwater management. While essential to prevent localized flooding, CSOs pose significant environmental and public health risks, particularly as extreme weather events become more frequent.

Nature-Based Solutions (NBS) have emerged as sustainable alternatives, leveraging natural processes to manage stormwater, enhance urban resilience, and provide multiple co-benefits. These green stormwater infrastructure strategies promote on-site storage, infiltration, and evapotranspiration, offering greater adaptability to changing precipitation patterns while delivering co-benefits such as enhanced urban biodiversity and improved quality of life (Grimm et al. 2017). However, the successful implementation of NBS requires more than technical solutions; it necessitates supportive governance structures and policy frameworks. (Martin et al. 2021)

Effective urban governance is crucial for integrating NBS into existing infrastructure and planning processes. Studies have shown that collaborative governance models, which involve multiple stakeholders, are essential for the successful adoption of NBS in urban settings (Frantzeskaki 2019; Mahmoud and Morello 2021). Their multi-functional aspect is one of their core qualities (Hansen et al. 2019). Policy frameworks that promote integrated water management and encourage the use of NBS can facilitate the transition towards resilient urban water management systems.

As part of the NICHES project, this report aims to identify and enhance the role of urban governance in integrating NBS into local policy frameworks. By examining the enabling and hampering conditions in the policy and governance contexts of five cities—Rotterdam, Barcelona, Berlin, Sheffield, and Boston—this analysis aims to highlight the best practices and lessons learned in NBS implementation. Through these insights, the report seeks to maximize the effectiveness of NBS as a viable alternative for mitigating CSOs while addressing broader urban sustainability goals.

# 2 Theoretical framework

To describe the **governance and institutional frameworks** in which restorative NBS are implemented and understand the planning processes connected to NBS in the NICHES cities**,** we need to examine the water management and see how it is embedded in urban policies. For this purpose, we will first create a common understanding by explaining the analytical concepts behind this deliverable, namely the concept of **water governance** in general, including **direct and indirect** policy measures, water governance in respect to **NBS** and connected to this, the framework of **urban water social-ecological-technical systems (SETS)** along all three **stages of NBS.**

## 2.1 Water Governance

Governing water is inherently complex due to its role as a shared resource that covers environmental, societal, and economic domains (Akhmouch et al. 2017). This complexity arises from the interconnected nature of water systems, involving multiple stakeholders, governance levels, and sectors such as agriculture, energy, and urban development. Often, decisions affecting water ecosystems occur outside the water sector and fail to incorporate considerations of water management (Pahl-Wostl et al. 2020). For instance, the rapid increase in surface-sealing in many major cities to accommodate for the need of housing and street infrastructure has strong influences on infiltration, evaporation and the water supply of adjacent ecosystems. These challenges underline the need for multi-level and cross-sectoral governance in order to enable effective and sustainable water resources management.

The **water governance concept** can be defined as a system of political, social, economic, and administrative components, that takes into account the different actors and networks that help formulate and implement water policy and also involves formal (laws, regulations, and policies) and informal institutions (cultural practices and social agreements) (Pahl-Wostl et al. 2012; 2020). The governance structure includes formal and informal rules that regulate interactions between actors and change slowly over time, providing both stability and inertia to water governance. Despite its importance, there is limited comparative analysis of water policy implementation at the operational level (Pahl-Wostl et al. 2020).

### 2.1.1 Nature-based Solutions

Water governance has historically prioritized provisioning services, such as water supply for irrigation, which offer immediate socio-economic benefits. This focus often neglects regulating and supporting services, like water purification and groundwater retention, which are critical for maintaining ecological integrity (Russi et al. 2013). Overexploitation of provisioning services can degrade regulating services, leading to long-term negative impacts on ecosystems and human well-being (Howe et al. 2014). These interdependencies, often spatially and temporally complex, complicate water governance, particularly when coordination structures fail to align with ecological interconnections, creating governance "misfits" and externalities (Pahl-Wostl et al. 2020).

In this context, **NBS** in urban areas, when properly designed and managed, offer a sustainable approach to overcome some of these challenges while providing multiple benefits. NBS enhance regulating services by utilising natural ecosystems for water retention, filtration, and purification. For instance, urban wetlands or green roofs contribute to stormwater management, reducing common water runoff and sewage overflow (CSO) while creating habitat for native species (McPhearson et al. 2022). As a result, this reduces dependence on and prevents damage to traditional infrastructure, mitigates pollution, and restores ecological balance. With urbanization and climate change exacerbating CSO events, NBS offer sustainable alternatives to traditional grey infrastructure. By fostering a closer alignment between ecological processes and governance structures within a comprehensive framework such as SETS (see below), NBS contribute to more resilient, integrated water management systems in cities as well as to enhanced social capacity, place-making, physical and mental health (Boros & Mahmoud 2021).

### 2.1.2 Direct and Indirect Policies

This research distinguishes between **direct** and **indirect policies** by analysing their relevance to NBS and CSO management. Direct policies are typically focused on achieving specific outcomes closely related to NBS. This may include regulations, standards, or guidelines that mandate or encourage the application of nature-based interventions or regulate discharge quantities. For instance, they might dictate how green infrastructure, reforestation projects, or wetlands restoration should be implemented to achieve environmental, social, or economic benefits. Direct measures can also take the form of targeted funding mechanisms, such as grants, subsidies, or other financial incentives, which are explicitly designed to support the deployment, maintenance, or scaling of NBS initiatives.

Indirect policies, on the other hand, are less explicit in their focus on urban water NBS but are also important as they create a supportive framework that fosters their adoption. These policies or actions may not mention NBS directly, yet they contribute to creating an enabling environment that makes the integration of nature-based approaches more feasible. Examples of indirect policies include urban planning frameworks, climate adaptation strategies, or economic development programs that highlight sustainability goals. Such measures might encourage cross-sectoral collaboration, increase awareness, or provide the institutional support necessary for NBS to be effectively incorporated into broader decision-making processes.

## 2.2 SETS Framework

This report situates itself within the **Socio-Ecological-Technical Systems (SETS) framework**, acknowledging the dynamic interactions among urban systems, including people, nature, technology, infrastructure, and governance. The NICHES project utilises the SETS approach (Figure 1) to recognize innovative ideas for water management in cities with the aim of increasing the resilience and sustainability of urban waterscapes and aquatic biodiversity. By bridging various sectors of urban planning and governance, this approach helps better understand and introduce multiple dimensions of NBS - the technical (the built technical-engineering structures, materials), ecological (climate-biophysical-ecological elements), and social (social-cultural-economic-governance structures) - in urban environments.Ecosystem services can act as a useful starting point for aligning the diverse outcomes of SETS interactions at regional and city contexts, helping to navigate ecosystem complexity and address sectoral fragmentation, thereby reducing siloed efforts in urban sustainability initiatives (Cadenasso & Pickett 2008; McPhearson et al. 2022).

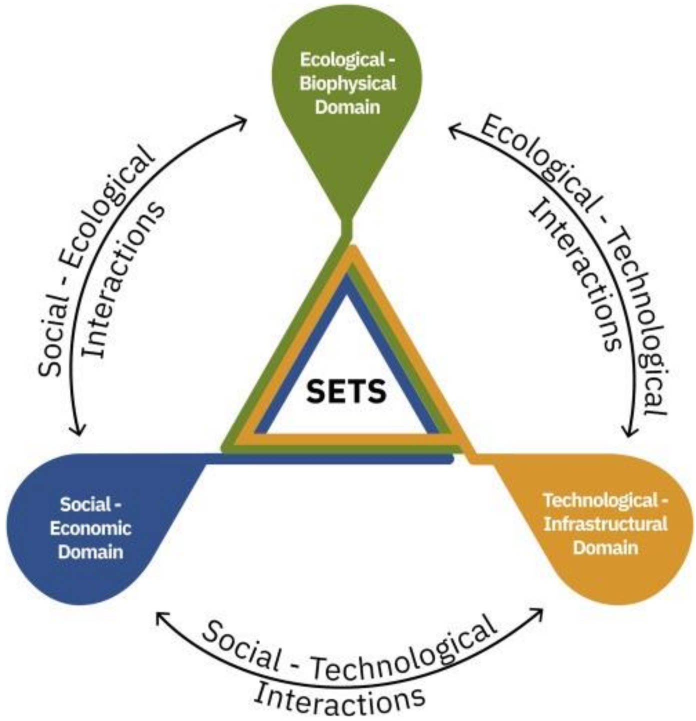


*Figure 1: The social-ecological-technological systems (SETS) conceptual framework. Source: McPhearson et al. (2022)*

The SETS approach extends beyond traditional views of ecosystem services as solely ecological phenomena or the result of social-ecological system dynamics. Instead, it acknowledges that for ecosystem services to effectively enhance human well-being, they require support from technological infrastructure, social institutions, and governance systems to ensure equitable access and distribution of benefits (McPhearson et al., 2022). For example, this is the case for bioswales, retention basins, and other hybrid interventions that should integrate social, ecological, and technological approaches throughout design, construction, and management, since these factors influence the ecosystem services and value of stormwater management (ibid.).

In addition, SETS helps identify critical couplings among ecosystem services. McPhearson et al. (2022) put forward a hypothesis that ecological-technical coupling is often more crucial in stormwater management than the social dimension. Specifically, in low- to medium-density urban areas, the success of bioswales often hinges on the retention capacity of engineered infrastructure and the ecological performance of soils and vegetation, with human management and local stewardship having a lesser impact.

However, with higher density of urban areas, the role of governance processes can increase. As the NICHES case study cities are all densely populated areas, we argue that the social and political dimension of SETS are core for successful implementation and long-term development of NBS in the urban water sector.

The technical infrastructure, such as engineering specifications of roofs and installation of irrigation systems, are claimed to be important for initial green infrastructure installation and establishment of primary benefits while the social dimension of NBS, including governance settings, is believed to grow in importance over time (ibid.). At the same time, Branny et al.

(2022) highlight the role of the social dimension in the smart and green city transition promoting the shift from traditional technocratic planning practices towards more democratic models of governance, which aligns to the social co-benefits surrounding NBS.

### 2.2.1 The three stages of NBS implementation

It is of critical importance that we make a clear separation understanding along the three stages of NBS. Understanding the SETS framework is critical for planning, implementing, and maintaining NBS in urban water management. In each stage of the NBS process, different governance instruments play a role, influencing how SETS are integrated and the outcomes achieved.

1. The **planning and design stage** engages stakeholders in developing and revising strategic and operational plans for NBS in urban water management, establishing procedures to guide implementation.
2. The **implementation stage** puts these policies, plans or rules into action by developing specific NBS measures, involving capacity-building initiatives like stakeholder training.
3. The **maintenance and management stage** focuses on operational activities and management actions to sustain NBS effectiveness, ensuring their long-term contribution to improving urban mixed sewage water management.

# 3 Methodology

The methodology for identifying and understanding the governance and institutional frameworks, in which urban SETS in all five NICHES cities are evolving consisted of data collection and various data analysis steps (Figure 2).

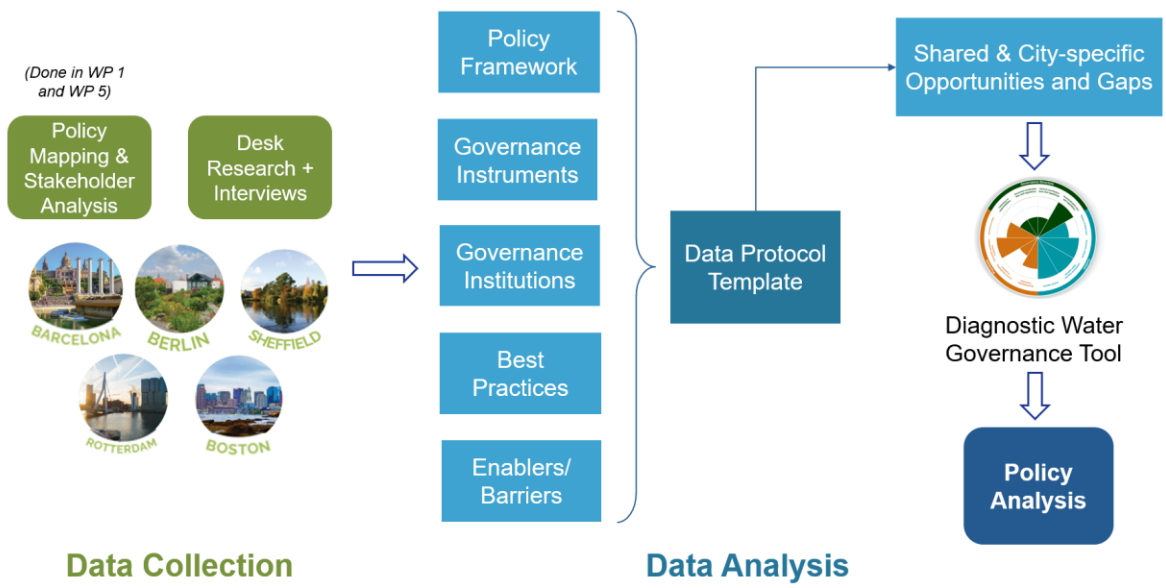


*Figure 2: Methodology of D.4.2 Policy Analysis. Own figure.*

## 3.1 Data Collection

The work on deliverable 4.2 built on previous analysis done in WP1 (policy mapping and stakeholder interviews) as well as the stakeholder mapping conducted in WP 5. The methodology of the data collection process conducted for D.4.2 was carefully outlined in Task 4.2. “Governance and institutional frameworks – Guidance for Niches cities” (Fuchs, Stein, Naumann, 2023). The process involved the work with primary and secondary information sources and consisted of the following steps:

- **Desk research and literature analysis** involved reviewing existing processes, policy, legal and financial instruments on NbS at the city level dating back to the year 2000 or earlier depending on the specific case study. The process included screening of the websites of the responsible authorities for relevant policy publications at city and regional level and if available at case study specific NBS intervention level.
- **Interviews** with diverse stakeholders—ranging from city officials to NGOs—provided varied perspectives on governance and policy approaches and their impact on urban water management practices in all 5 cities. For this step, knowledge gathered from previous tasks (e.g. stakeholder mapping, interviews conducted throughout stakeholder workshops in Rotterdam, Berlin and Barcelona) was utilised to efficiently use existing resources and minimise the potential for stakeholder fatigue. Additional five interviews with experts from local academia and authorities have been conducted, where information was missing. The guidelines for conducting interviews as part of Task 4.2., including consent and ethical guidelines, were shared with the partners to ensure the consistency of the approach. These guidelines also included the set of city-specific questions that could be specified and adapted.
- **Reporting**: the outcomes of the interviews were documented either as a full transcript or as bullet point notes and later on summarised in a consolidated data protocol template

## 3.2 Data Analysis

### 3.2.1 Data Protocol Template

To systematically gather and analyze the collected information, the governance and institutional frameworks ***data protocol template*** was developed as a data analysis tool. The data protocol consisted of five sheets within the Excel document: **1. policy framework, 2. governance instruments, 3. institutions and institutional processes, 4. best practice examples,** and **5. barriers and enablers**. In each sheet, all information gathered per city was noted down, ensuring a holistic overview of the individual governance aspects compared per city (Figure 3). Below, we further describe the contents of each of the sections:

1. To describe the **policy framework** in place to address CSO and management of urban sewage water in each of the cities, relevant (direct and indirect) policies, strategies, or management approaches were included in the corresponding table. Important information included amongst others the **Scale/ boundary** of the policy, (citywide, catchment area, etc.), the **objective**, (reducing CSO volume, improving water quality, etc.), the i**mplementation approach**, **achieved outcomes** and m**onitoring processes**

2. For understanding **governance instruments** that are applied at different stages of NbS process, the analysis criteria were selected in line with SETS framework and describing the different **stages of NBS process**: 1. Planning and design, 2. implementation and 3. Maintenance. Moreover, it was noted which **type of (governance) approach** (traditional or more innovative, (de)centralized, participatory, top-down etc.) prevailed, what **type of collaboration** (horizontal, vertical) existed**.**
3. Additionally, the **institutions and institutional processes** in the NBS governance and management were evaluated. This description was conducted based on the following assessment criteria: **Actor roles**, their **coordination** and cooperation, **accountability** of those institutions, **power dynamics,** and the level of **influence of civil society** has upon them.
4. Based on this information, **best practice examples** of policy and governance approaches in the implementation of integrated and sustainable urban sewage water management were identified. For this purpose, a "best practice example" was defined as a policy or governance approach that provides effective, innovative, and sustainable solutions to urban water challenges, with due regard to the principles of NBS. The examples were assessed according to their scope, effectiveness, innovative aspects (e.g. the use of novel technologies) their **success factors** (e.g., stakeholder engagement, policy support, etc.) and their **potential for up-scaling and transferability.**
5. Finally, the last assessment section dealt with potential **barriers and enablers** that impact the effective governance and institutionalization of urban NBS for CSO management, throughout the **different stages of NBS process**. The investigation spanned various factors including, but not limited to, regulatory frameworks, bureaucratic procedures, conflicting interests, stakeholder priorities, and power dynamics. Each barrier and enabler was **described** separately according to its **type** - examples include regulatory, financial, societal, bureaucratic, technical barriers or enablers. It was assessed what **impact** the barrier or enabler had on the implementation of NBS, including who is affected and how. Finally, **strategies to overcome or utilize** the barriers or enablers were gathered.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Policy Framework** | Name/ Description | Scale/ Boundary | Objective | Implementation Approach | Achieved Outcomes | Monitoring | Strengths/ Weaknesses | Opportunities for Improvement/ Increased Impact |
| **Governance Instrument** | Name/ Description | Stage of NBS Process | Type of Governance Approach | Centralization | Type of Collaboration | Nature of Approach | Initiative Origin | |
| **Institutions and Processes** | Institutional Structures and Processes | Actor Roles | Coordination and Cooperation | Accountability and Monitoring/ Enforcement | Power Dynamics/ Autonomy and Influence | Adaptability | Social Dimension | |
| **Best Practice Example** | Description and Scope | Policy Instruments | Effectiveness | Innovative Aspects | Sustainability | Success Factors | Learning | Crisis and Resilience |
| **Barriers/ Enablers** | Stage of NBS Process | Type of Barrier/ Enabler | Description | Impact | Strategies to Overcome/ Utilize | | | |

*Figure 3: Set-Up of Data Protocol Template with analysis categories. Own figure.*

For ***validation purposes***, the data that has been transferred from interviews and desk research to the analytical data protocol template has been presented and re-assessed with the consortium partners for their respective cities throughout multiple meetings.

### 3.2.2 Diagnostic Water Governance Tool

As an additional analysis step, the data has been transferred into the ***Diagnostic Water Governance Tool (DWGT)***[1], which was developed in the STEER Project (Stein et al. 2023). The conceptual framework behind the DWGT focuses on cross-sectoral water resources challenges and on questions of coordination and cooperation to address these issues (Pahl-Wostl et al., 2020). Through answering a predefined set of questions based on expert judgement, the tool allows for an assessment of the water governance and management system of a specific case study, evaluating processes, governance structure and context in a pie chart. 'Context' comprises all overarching societal and environmental factors that may influence, but can hardly be influenced, by the water governance and management system. 'Governance structure' includes formal and informal rule structures that regulate interdependencies between actors and change only slowly over time. 'Processes' looks at policy implementation rather than the development of formal institutions. The final "diagnosis" evaluates these sections from low to high performance (Figure 4). The auto-generated pie-charts allow for a visual comparison between the case studies, pointing out opportunities of cross-city learning.


*Figure 4: Evaluation scale of DWGT. The length of a sector represents the value of the respective variable (low to high). Source: watergovernancetool.eu*

The distinction between vertical and horizontal coordination in 'theory', that is: in laws and regulations, and the coordination 'in practice' is particularly relevant to understand for the result and discussion section (see Table 1).
Also the criteria of Decentralization can be differentiated 'in theory' and 'in practice'. Decentralization characterizes the distribution of decision-making authority within a system across its constituents. This can happen vertically, where decentralization delineates the delegation of formal decision-making capabilities down the hierarchical line of authority, as well as horizontally, which indicates the diffusion of decision-making power informally beyond the established hierarchical structure (Mintzberg, 1980). In simpler terms, Centralization in this context implies that lower and intermediate levels of government have little to no independent authority over water resource management decisions, while decentralization signifies that they possess significant or complete autonomy in these matters.

[1] https://www.watergovernancetool.eu/

*Table 1: Criteria per Category used in the DWGT. (Table modified from Stein et al. 2023 and Pahl-Wostl et al. 2020)*

| Name DWGT Criteria | Explanation |
|---|---|
| ***Processes*** | |
| Decentralization in practice | Extent to which lower and intermediate levels of government are autonomous in decision-making and implementation for their respective level to address the water resource problem. |
| Vertical coordination in practice | Extent of coordination instruments used effectively to align interests and activities of actors at different governance levels with respect to the water resource problem |
| Horizontal coordination in practice | Extent of coordination instruments used effectively to align interests and activities of actors from the water sector and department and the other relevant sector(s) and departments with respect to the water resource problem. |
| Governance modes | Extent to which a single governance mode is dominating. Governance modes refer to the realized governance style in terms of a hierarchy, network or market governance logic. |
| ***Governance Structure*** | |
| Coherence of responsibilities | Extent to which laws and regulations of the water sector clearly allocate responsibilities among actors and clearly regulate potential overlaps of responsibilities |
| Vertical coordination according to laws and regulations | Extent to which laws and regulations of the water sector specify coordination instruments to align interests and activities of relevant actors at different governance levels. |
| Horizontal coordination according to laws and regulations | Extent to which laws and regulations of the water and the other relevant sectors specify coordination instruments to align interests and activities of relevant actors from these sectors |
| Decentralization according to laws and regulations | Extent to which laws and regulations of the water and the other relevant sectors specify efforts for autonomous decision-making and implementation for lower and intermediate levels of government. |
| ***Context*** | |
| Human Capacity | Skills, knowledge, expertise, and personnel resources needed within the relevant authorities to effectively implement and manage a particular water governance instrument |
| Institutional capacity / State capacity | Institutional: Value of the Corruption Perceptions Index in 2016 (Transparency International, 2018)<br>State: Value of the Government Effectiveness Indicator in 2016 (World Bank, 2019) |
| Economic Capacity | |
| Degree of Democracy | Value of the Economist Democracy Index in 2016 (Economist, 2019) |

# 4 Case Study Descriptions

To understand the Results and Discussion sections in the following chapters, a brief introduction of the case study cities is necessary to better understand the context in which certain policies or institutions have been created.

**Barcelona**

The Metropolitan Area of Barcelona in eastern Spain encompasses Barcelona city and 35 nearby municipalities, covering 636 km² with a population of approx. 3.3 Mio. (AMB 2023). Half of this population resides in Barcelona itself. The city lies between the Besòs and Llobregat rivers, Montserrat mountain range and the Mediterranean Sea. In relation to climate change the city will face reduced water availability, a rising sea level, increased flooding and deterioration of water quality in receiving water bodies (Ortiz et al. 2020). While major 100-year flood events are rare in these rivers, flooding (often flash-floods) from heavy convective local precipitation in late summer and autumn occurs annually, impacting both urban and rural areas due to drainage problems (Moral et al. 2017, Cortes et al. 2018). The combined sewer systems (CSSs) in Barcelona are not capable of the collective management of wastewater and stormwater during such high rain events, leading to environmental impacts through combined sewer overflows (CSOs) occurring in rivers and the sea. These overflows result, amongst others, in polluted beaches, causing economic losses for a city heavily reliant on tourism and endangering the city's image (Martínez-Gomariz 2021).

**Boston**

Boston, the capital of Massachusetts, spans approx. 125 km² in the North-East of the United States. Facing increasing threat of sea level rise (Kirshen, Knee, & Ruth 2008), the flood-prone city has implemented various shoreline stabilization structures, such as seawalls and revetments along the 76 km long coastline (City of Boston 2024). Coastal Massachusetts is sinking at a rate of 1.5 mm per year, amounting to roughly 15 cm over the last century (Nucci Vine Associates 1992). Once known for its severely polluted harbor due to wastewater treatment plant effluent and CSO events (Taylor 2010), Boston has significantly improved water quality through Massachusetts Water Resources Authority (MWRA) initiatives since 1985. Nowadays, the city is served by both, a separated wastewater collection system and a combined one, the latter being replaced successively over the years (BWSC, n.d). A major milestone was the 2000 opening of a 14 km tunnel redirecting wastewater to Massachusetts Bay, reducing CSO volumes by over 86% (Cantwell et al. 2016). However, CSO challenges persist. In May 2023, untreated overflows at two locations and a treated discharge at Outflow prompted public health warnings to avoid affected waters for 48 hours due to potential bacterial contamination.

**Rotterdam**

Rotterdam, located in the southwestern Netherlands, covers 200 km² and has a population of 670,610 (CBS 2024), making it the country's second-largest city. The River Nieuwe Maas, a northern distributary of the Rhine, is shaping the city scape and ending in the North Sea, where the city is home to one of the largest ports in the world. With 80% of the densely populated city below sea level, Rotterdam relies on dykes for protection (RCI, 2013). This is aggravated by the challenge of river flooding caused by upstream rainfall patterns and consequent effect on downstream sea level rise. CSO events and stagnant water is degrading urban surface water quality annually. Much of the sewer infrastructure dates back to post-war reconstruction in the 1950s and 1960s. While in new urban areas separate sewer systems are deployed, a significant 70% of the annual runoff still enters the WWTPs. Groundwater leakage is causing additional increased flows to wastewater treatment plants (WWTPs). Pressurized pumped overflows to the adjacent rivers increase controllability of the system, yet they provide limited relief during excessive rainfall events to the cities surface water (Geerse & Lobbrecht 2002). Unlike Barcelona and Boston, Rotterdam lacks public beaches but offers recreational access to urban canals and lakes, through which inhabitants are exposed to potentially contaminated water.

**Berlin**

Berlin, the capital of Germany, covers approximately 891 km², making it one of the largest cities in Europe by area. As of 2024, it is home to about 3.9 million residents and Germany's most populous city (ASBB, 2024), located in the North-East of Germany. Berlin is characterized by its network of waterways, including the Spree and Havel rivers, and numerous lakes, which contribute to its urban landscape and offer recreational sites for inhabitants. Despite a well-established stormwater management system, the challenge of urban flooding during intense rainfall events persists. Berlin's historical infrastructure, much of which predates modern hydrological demands, faces pressures from increased impervious surfaces and climate change impacts and remain inadequate to manage the annual discharge of 3–4 Mm³ of untreated wastewater, affecting lake ecosystems and threatening drinking water quality (Wild et al. 2024). Regular massive fish deaths have been reported during heavy rainfall events, when the overburdened sewer system discharges into the river Spree (Lowitzsch 2017).

**Sheffield**

Sheffield, located in South Yorkshire, in the center of England, spans an area of approximately 368 km² and had a population of about 556,500 as of 2023. Known for its hilly terrain and multiple channels and streams such as the river Don and the Sheaf, Sheffield's hydrology plays a significant role in shaping its urban environment. Historically an industrial hub, the city’s waterways were heavily impacted by pollution, but substantial restoration efforts over recent decades have improved water quality, driven by European legislation through the Water Framework Directive (2000/60/EEC) (Ashley et al. 2010). Flood risk remains a concern, particularly from riverine flooding exacerbated by upstream rainfall and urban runoff. Sheffield has implemented various flood defense measures, including sustainable drainage systems (SUDS) and community-driven initiatives, to enhance resilience. However, water quality issues remain pressing, as sewage discharge into river systems by CSO events have been increasing by 33% in 2024 compared to the previous year (Gregory 2024).

# 5 Results: City Specific Governance Systems

## 5.1 Barcelona

*Overarching Policies and Frameworks: Ambition vs. Integration*

Barcelona has been actively pursuing the integration of NBS and green infrastructure in their governance framework to mitigate the impacts of CSOs and enhance urban resilience. The city has developed several direct and indirect policies aimed at urban resilience, water reuse, and ecological sustainability. Plans such as the **Metropolitan Urban Master Plan (PDU) (2019), the Strategic Plan for the Integrated Water Cycle of the Barcelona Metropolitan Area 2023 (PECIA), Climate Change Adaptation Plan (2018-2030)** and the **Action Plan for Climate Emergency (2030)** reflect an overarching ‘master planning’ and commitment to sustainable urban water management in the face of climate change. However, these frameworks often lack integration. For example, the PECIA Plan, while holistic in its approach to water sources and future adaptability, does not adequately link urban green spaces to water management. Similarly, the **Natura Barcelona 2030 Plan**, a participatory effort to develop ecological green infrastructure, fails to address its role in managing water demand and CSOs.

Barcelona benefits from a mix of long-term strategies, such as the **Integral Master Plan of Sanitation of Barcelona (PDISBA)**, and short-term actions like the **Technical Plan for the Use of Alternative Water Resources (PLARHAB 2020)**. PDISBA offers an 80-year vision for flood mitigation and CSO management but focuses predominantly on grey infrastructure, such as anti-flood tanks and sewer upgrades, with limited emphasis on immediate, actionable steps. PLARHAB on the other hand provides a direct policy mechanism for promoting the use of alternative water resources, including groundwater, rainwater, and gray water. The achievements can already be seen in the increased use from 2% of regenerated water in 2019, to 30% in 2024. While a policy mix of long-term and short-term strategies allows for a greater adaptability of measures, stronger alignment and interlinkages between the policies could strengthen their impact, for instance a stronger integration of PLARHAB with local sanitation policies.

None of the above-mentioned policies started as bottom-up initiatives. However, the PLARHAB specifically points out that stakeholder participation was an integral component in the policy creation process, indicating a participative approach in the development and in all phases of the preparation (BCASA 2020). The involvement of various stakeholders, experts and sectors involved in the municipal water management guaranteed transparency and accountability towards the public.

*Coordination and Fragmentation in Institutional Processes*

Barcelona's governmental instruments include subsidies and programs aimed at engaging private stakeholders, particularly in implementing green roofs and water recycling systems. However, these instruments often focus on the planning and design phases of NBS, leaving gaps in long-term maintenance and monitoring. **The City Council** provides financial subsidies and often serves as central oversight and monitoring organ for other departments or agencies. The **Comisión de SUDS del Ayuntamiento de Barcelona** (*City Council SUDS Commission*) plays a critical role in designing and reviewing SUDS projects, integrating natural processes such as infiltration and storage into stormwater management. This commission collaborates with institutions like **BCASA (Barcelona Cicle de l'Aigua)** and the **Department of Ecology, Urban Planning, and Mobility**, providing training to stakeholders to overcome the technical complexities of NBS implementation.

BCASA exemplifies vertical coordination by bridging municipal and regional policies and leveraging external funding from entities like the Catalan Water Agency and the European Union. BCASA engages in public awareness campaigns to educate citizens about water conservation and NBS, fostering local participation. Barcelona Regional Agency is another important advisory, connecting authorities and private entities. However, the agency's reliance on oversight and funding from the City Council limits its autonomy. This is also reflected in the DWGT analysis pie-chart of Barcelona (Figure 5), where the vertical coordination in law and regulation is evaluated higher than in practice, where it is partially blocked by the supervision and general direction-giving role of the city council, almost like a bottleneck. While the multitude of different policies, instruments, agencies and institutions with high stakeholder participation suggest a very decentralized approach in theory, most of these institutional processes are ultimately centered under the city council, leading to a slightly lower ranking of decentralization in practice in Figure 5.

A strong facilitator horizontal coordination across sectors such as mobility, ecology, and urban planning is however the above-mentioned Department of Ecology, Urban Planning, and Mobility, which is particularly responsible for integrating NBS into urban projects. It is responsible for ensuring that urban policies align with Barcelona's long-term sustainability goals. While this department is actively working on cross-departmental coordination, it can be argued that the sheer number of governmental institutions involved in similar initiatives in Barcelona can lead to overlapping efforts and inefficiencies.

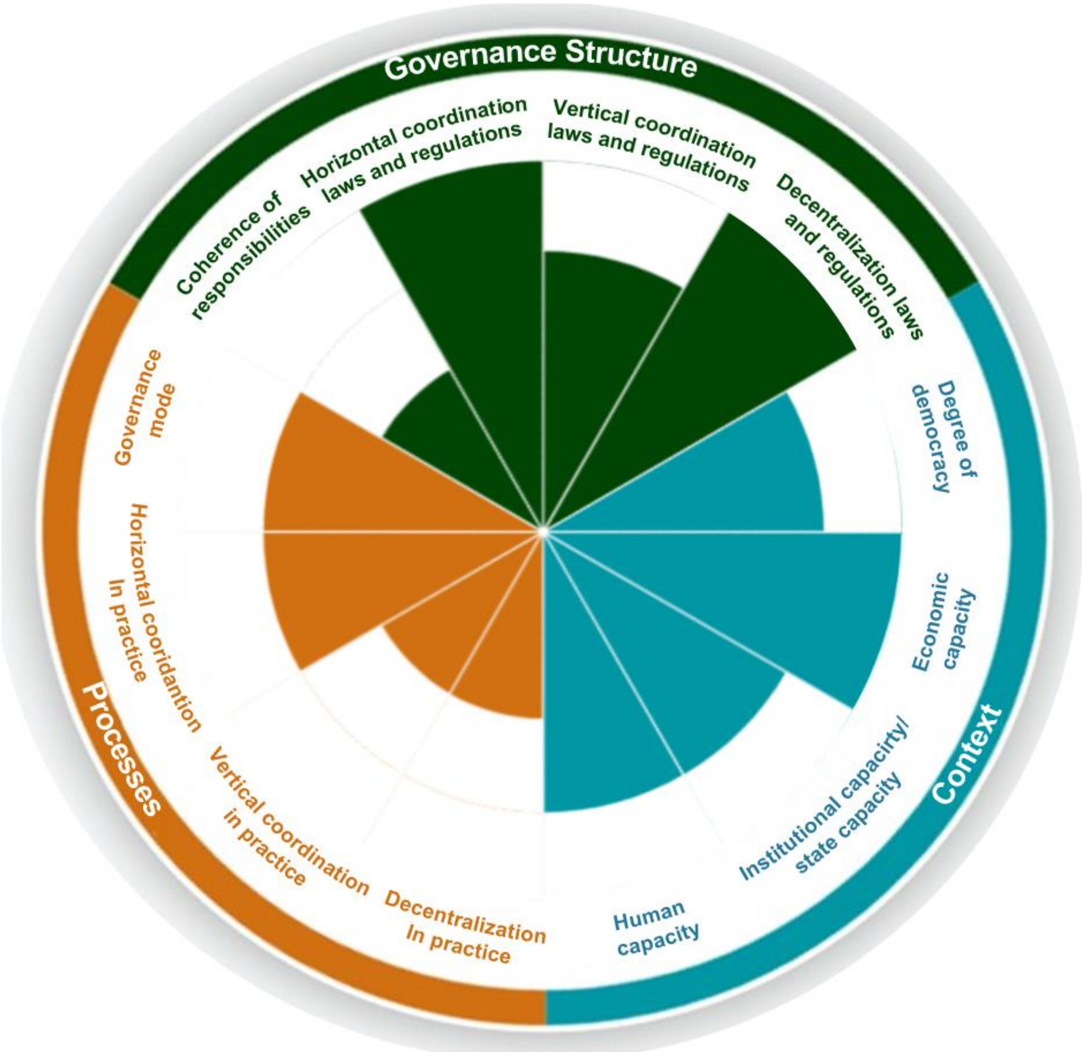


*Figure 5: DWGT Analysis Pie-Chart of Barcelona*

Despite the various promising governance instruments and policies, challenges persist in fully integrating NBS into urban planning. A 2023 study highlighted that the fragmentation of responsibilities within technical and administrative services in Barcelona, along with rigid structural conditions, hampers the effective implementation of NBS and their co-benefits (Kauark-Fontes, Marchetti, Salbitano 2023). This siloed approach can lead to missed opportunities for cross-sectoral collaboration and holistic water management strategies.

Another obstacle to NBS implementation is the **lack of public concern**: CSOs have not garnered significant public attention compared to issues like drought and beach erosion. This lack of awareness undermines public support for NBS targeting stormwater regulation. Moreover, the need for irrigation in green infrastructure projects poses a conflict with Barcelona's efforts to conserve water, particularly during droughts. From this conflict derives also a chance: political interest in *efficient* water management is high in Barcelona, and the promotion of alternative water sources can be strategically expanded to the maintenance of green infrastructure projects.

## 5.2 Boston

Though the *technical* component of Boston's SETS seems to prevail, with large scale grey infrastructure that has been implemented over the last decades, the social dimension in form of governance settings have indeed grown in importance over time as suggested by McPhearson et al. (2022). Boston's stormwater management is underpinned by the robust regulatory framework of the **National Clean Water Act (CWA),** dating back to the 1970s. This federal law, enforced by the U.S. Environmental Protection Agency (EPA), sets national water quality standards and has driven significant investments in grey infrastructure, including Boston's system-wide storm source separation. Approximately 90% of the city's system has been separated following court-mandated compliance, leading to the installation of underground storage tanks and improved water quality. **Public litigation** has played a pivotal enabling role in enforcing CWA standards, highlighting the US-American reliance on legal mechanisms to spur action.

**Stormwater Management Ordinances** and related permitting systems require new developments in Boston to incorporate on-site stormwater treatment measures on public but also private land, including rain gardens and infiltration basins. These compliance-based instruments effectively shift the cost of NBS to private landowners, leveraging their participation in stormwater management at a relatively low expense compared to total construction costs.

Additionally, the **Total Maximum Daily Load (TMDL) Permit System** regulates pollutants in water bodies using historical water quality data and hydrological modeling by the EPA. While technically sound, the system's localized scope sometimes limits its application to broader stormwater challenges.

*Boston's Institutional Roles: Centralization and Coordination Challenges*

Boston's water governance is highly centralized, with the EPA setting national standards and coordinating with state and city agencies for implementation. The **Boston Water and Sewer Commission (BWSC)**, the city's primary water management agency, works in tandem with the **Massachusetts Water Resources Authority (MWRA)** to manage water distribution and wastewater collection. These agencies have implemented public notification systems to alert residents about CSO events, ensuring community awareness and safety.

The lack of coordination among various city departments continued to be a barrier, contributing to inefficiencies and delays in project execution. As a response, the city's **Office of Green Infrastructure** has been established (M. Eckelman, personal communication, December 21, 2023). It exemplifies horizontal coordination by aggregating demand for green infrastructure projects and applying for grants to fund initiatives across departments (see also Horizontal Coordination in Practice in Figure 6). This office has redefined infrastructure standards, incorporating stormwater management elements like rain gardens into road construction as a default practice. However, in an Interview with the Associate Professor of Environmental engineering at Northeastern University, Boston, M.Eckelman, it was discussed that in other departments such as the roads department and the park department overlapping responsibilities and a lack of knowledge exchange hinder effective NBS implementation and lead to inefficiencies (see also low score in coherence of responsibilities in Figure 6) (M. Eckelman, personal communication, December 21, 2023).

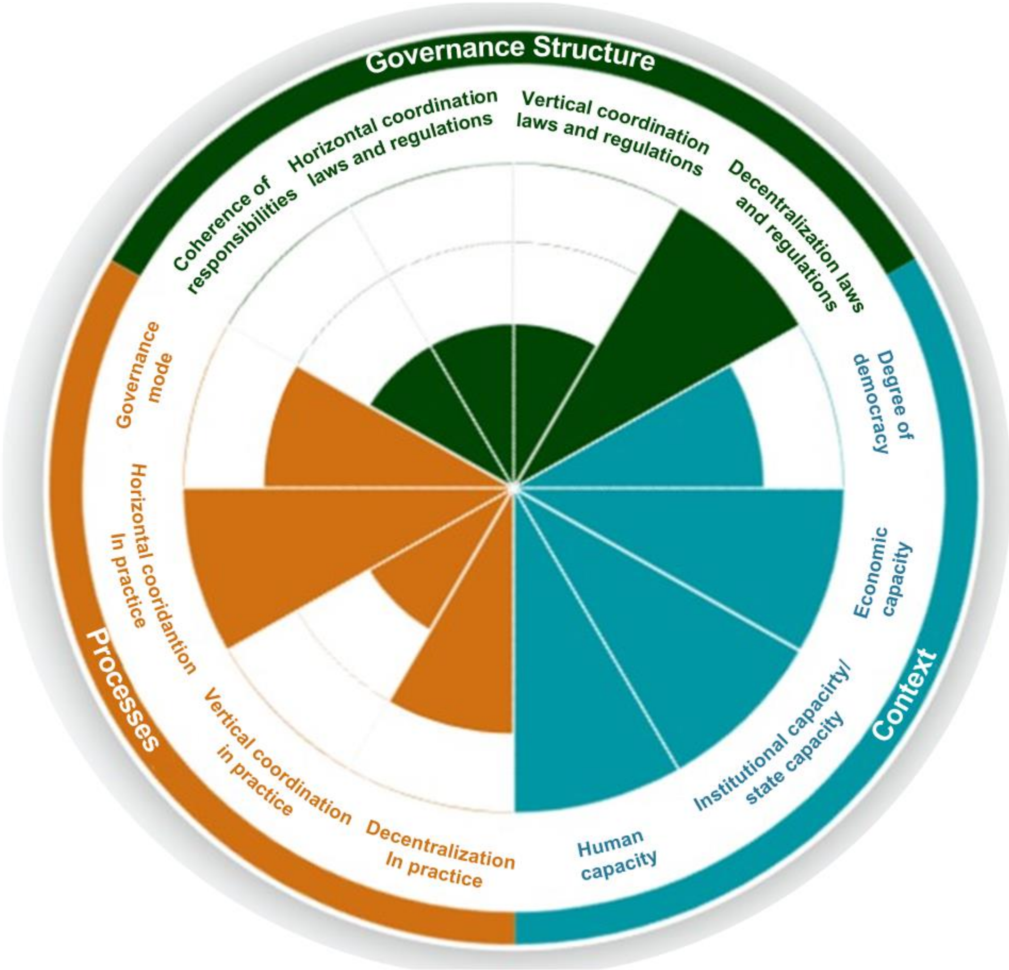


*Figure 6: DWGT Analysis Pie-Chart of Boston.*

While neighborhood initiatives like Green Teams, or the **Rosaline Clean and Green** showcase strong civic engagement, they lack formal responsibilities, which limits their scalability and integration into broader stormwater management strategies. Civic organizations and NGOs play a critical role in planning, lobbying, and designing NBS projects. However, slow implementation and limited integration into city-wide master plans undermine their effectiveness in the face of rapidly evolving climate change impacts. For example, Boston lacks a comprehensive master plan for stormwater management, focusing instead on parcel-level projects without considering long-term climate scenarios. The absence of a city-wide stormwater master plan results in disjointed efforts that fail to address the interconnected challenges of CSO mitigation and climate resilience. The city's **Standing Commissions** foster public participation through comment periods for new policies, promoting transparency and inclusivity in governance processes.

## 5.3 Rotterdam

Rotterdam's governance framework is shaped by overarching regulations such as the **Environmental Act (Omgevingswet)**, the **Water Act**, and the **Delta Program on Spatial Adaptation**. The Environmental Act, effective January 2024, aims to simplify and integrate spatial planning regulations, creating a single digital platform for stakeholders to access relevant rules across governance levels. This act facilitates vertical coordination by harmonizing policies between municipalities, provinces, water boards, and the national government, fostering efficient decision-making and empowering local customization. The new ‘**Environmental Desk’**, as part of the Environmental Act, is creating a unified digital environment for policy communication, enabling stakeholders to navigate regulatory landscapes more effectively. Different rules from the municipality, province, water board and national government that apply at a certain location can be found in one overarching platform. This creates a complete picture for citizens, companies and professionals of what is possible and permitted in their living environment. This digital tool can become a groundbreaking communication tool of local policies and regulations towards citizens and a great tool for vertical coordination. As the policy and tool just came into effect recently, its effect in practice is yet to be evaluated. Therefore, the evaluation between vertical coordination in theory and in practice in Figure 7 still shows discrepancies between rather high and high.

The **Waterkracht Alliantie** is a transdisciplinary collaboration platform and exemplifies both vertical and horizontal coordination. This alliance integrates efforts among the Rotterdam municipality, neighboring municipalities (e.g., Capelle aan den IJssel), water boards, and the private sector, including Evides Drinking Water Company. It focuses on efficient water management across the water chain, climate adaptation, and the integration of NBS into urban planning (horizontal coordination in Figure 7 rather high). The platform connects national, regional, and local authorities, aligning objectives across governance levels.

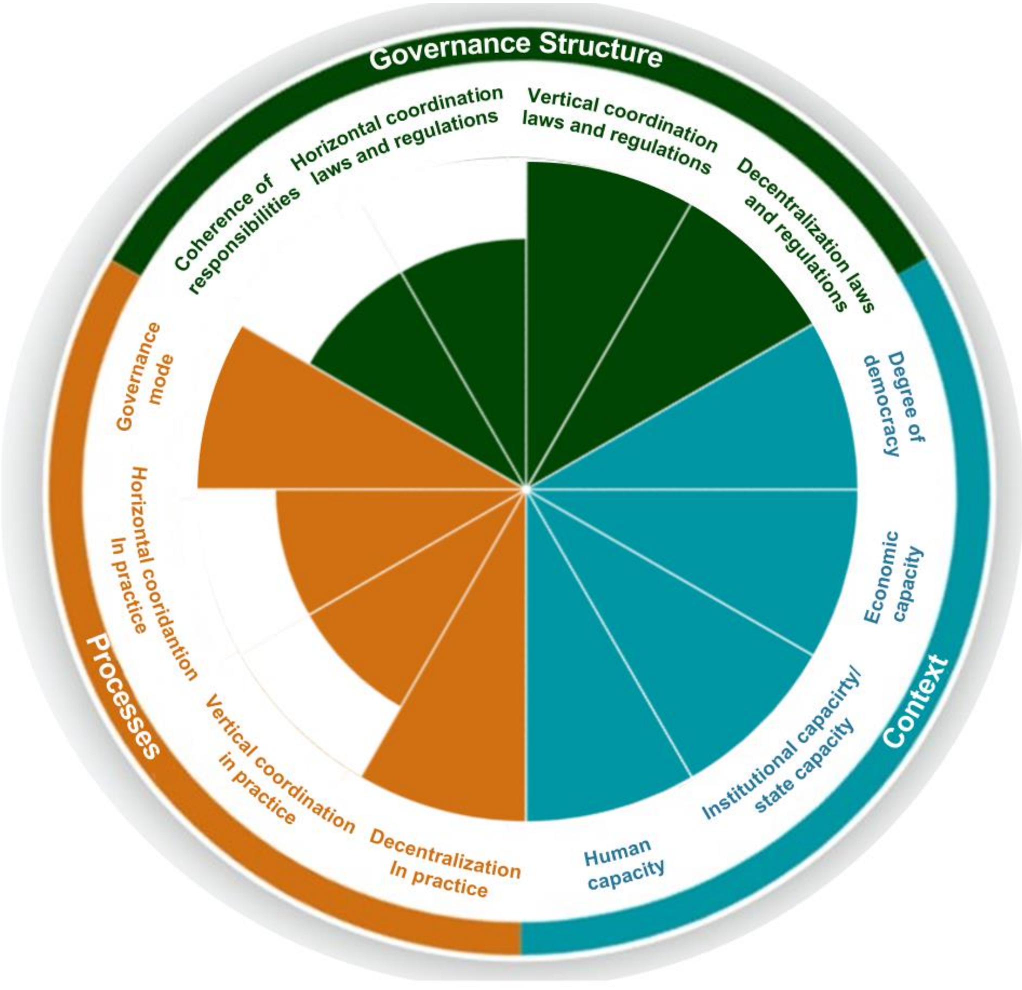


*Figure 7: DWGT Analysis Pie-Chart of Rotterdam.*

Rotterdam's local initiatives, such as the **Rotterdam WeerWoord (Rotterdam Weather Word/Response)**, align with the National Delta Plan on Water Safety to enhance climate resilience by 2050. WeerWoord mobilizes diverse stakeholders, including water boards, developers, social housing corporations, and residents, to implement climate-adaptive measures across scales. These initiatives exemplify the city's proactive approach to fostering participatory governance and bottom-up engagement.

The city demonstrates a growing commitment to integrating NBS into its water management strategies. Policies such as the **Rotterdam Subsurface Management Regulation (VBOR)** and the **Rotterdam Rainwater Regulation** mandate measures to manage rainwater on-site, reduce CSO occurrences, and prevent flooding. For example, VBOR requires rainwater storage facilities for new construction projects, with a minimum capacity of 50 mm and discharge limits to the municipal sewer system. In public spaces, the municipality of Rotterdam has a best-efforts obligation to collect, drain, and process rainwater. On private property, the owner is primarily responsible for the processing of rainwater (Article 3.5 of the Water Act). If plot owners cannot reasonably process rainwater on their own plot, they can connect to the public rainwater supply.

The policy and governance framework of Rotterdam is particularly comprised of a mixture of bottom-up and top-down initiatives, large scale measures and NBS on individual plots. For instance, the region wide **Delta Plan on Water Safety**, funded through the Delta Fund, primarily emphasize traditional grey infrastructure such as dike improvements. However, smaller-scale initiatives led by citizen organizations like **De Urbanisten** including guerilla rain gardens and sponge gardens, and national campaigns such as **Tegelwippen** (a national competition to reduce soil sealing) highlight the potential for innovative, small scale NBS to complement grey solutions and enhance urban resilience. The inclusion of the social dimension and decentralized collective action, stirred through these bottom-up, grassroot initiatives, is a powerful enabler in Rotterdams NBS implementation (see Decentralization in Theory and Practice in Figure 7).

However, many of the above-mentioned policies frame NBS mainly as long-term solutions rather than immediate actions, delaying their integration into current water management practices, reducing their potential impact on mitigating CSOs. Existing frameworks, such as the Municipal Sewerage Plan (2021-2025), do not explicitly prioritize NBS, additionally limiting their formal adoption in urban planning.
Finally, with 60% of the city privately owned, the lack of incentives for private landowners to implement NBS hinders broader adoption.

## 5.4 Berlin

Berlin’s water governance is shaped by a multi-layered policy and institutional framework that emphasizes sustainable urban water management and climate adaptation. At the intersection of federal and regional regulations, Berlin is advancing the implementation of NBS to address above mentioned urban water challenges, including the mitigation of CSO events.

The **Nationale Wasserstrategie**, a national water strategy introduced by the Federal Ministry for the Environment, reinforces these efforts through a comprehensive set of measures aimed at achieving water-sensitive urban development by 2030. Berlin’s alignment with this national vision and ‘master planning’ demonstrates its focus on building climate-resilient urban infrastructure.

The **Wasserhaushaltsgesetz (WHG)**, Germany's federal water law, provides the foundation for water governance by transposing the European Union’s Urban Wastewater Treatment Directive into national legislation. This law mandates that rainwater from impervious surfaces be managed in ways that preserve public welfare and emphasizes infiltration as a preferred approach. While the WHG adopts a comprehensive stance on water management, it could be strengthened by explicitly promoting NBS and integrating principles of the circular economy, which would align water resource management with broader sustainability goals.

Building on this federal framework, the **Berlin Water Act (BerlWG)** tailors these principles to Berlin’s unique urban context, establishing standards for wastewater and stormwater management. Complementing these laws is the **Coalition Agreement of 2017**, a key policy that prioritizes decentralized rainwater management. Under this policy, all new residential areas in Berlin must adopt local rainwater retention and infiltration measures. Additionally, the city aims to disconnect 1% of its urban surfaces annually from the mixed sewer system. While still far from achieving its full potential, this policy underscores a long-term commitment to sustainable water practices and fosters innovation, such as the Sponge City concept. The policy’s success depends on scaling up these measures to achieve significant surface disconnection, with anticipated impact becoming evident when 20–40% of surfaces are decoupled from the mixed sewer system.

The institutional landscape in Berlin further supports the city’s water governance objectives. The **Berliner Wasserbetriebe (BWB)**, the primary water management authority, plays a central role in integrating NBS into urban planning. Through strategies such as the Berliner Rainwater Concept and the Sponge City Strategy, the BWB implements decentralized rainwater management solutions while collaborating with public agencies, private enterprises, and residents. For example, community-driven initiatives, such as the creation of rain gardens, highlight how local engagement can facilitate sustainable practices.
BWB also leverages tools like the **Digital Planning Table** to enable interactive, collaborative planning for decentralized water solutions, enhancing the design and implementation of NBS. Supporting these efforts is the **Berliner Regenwasseragentur**, a networking and advisory body dedicated to sustainable rainwater management. Acting as a communication hub, the agency facilitates knowledge exchange among stakeholders, including city planners, property

owners, and contractors. This vertical coordination is critical to the successful integration of NBS into Berlin's water infrastructure (see Vertical Coordination in Practice Figure 8).

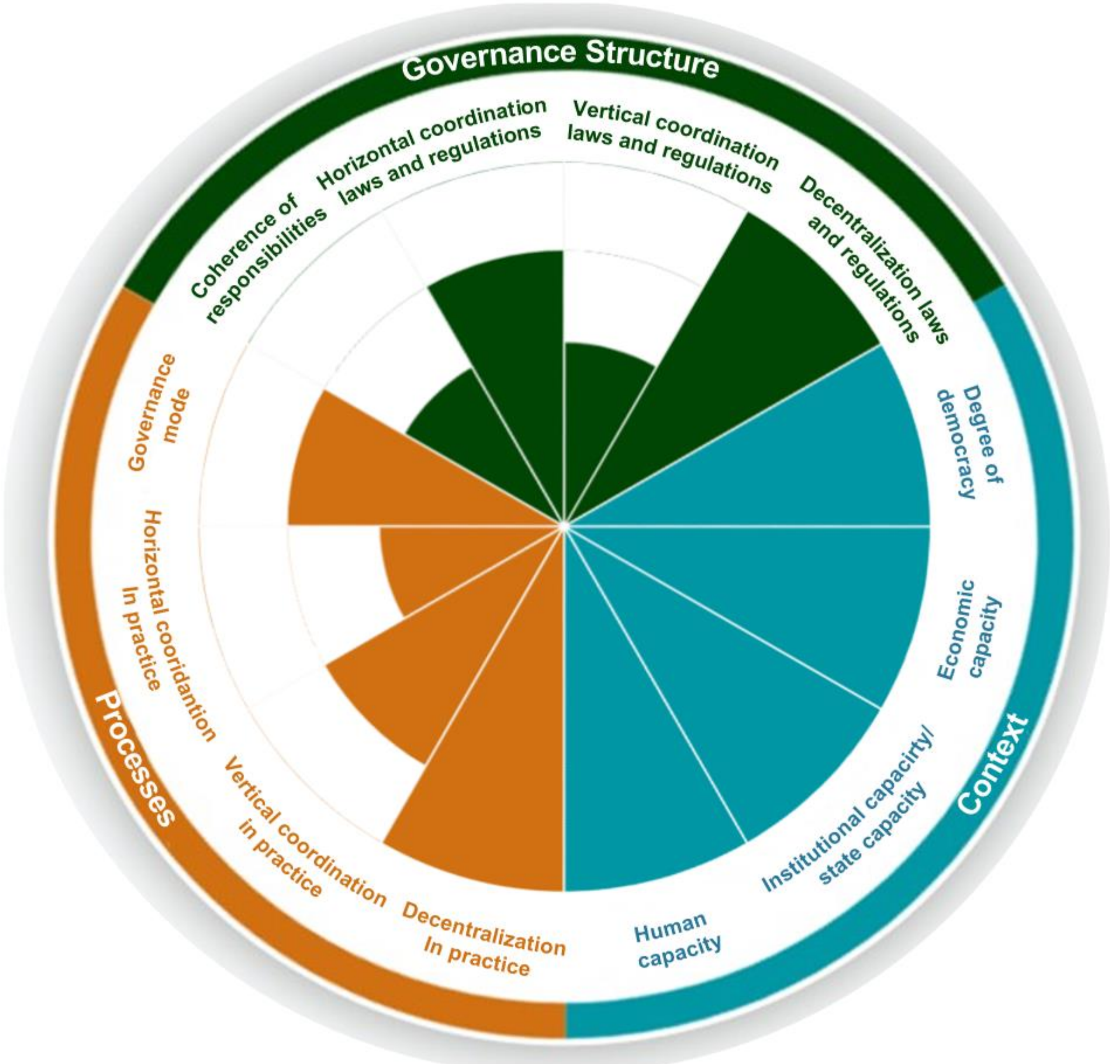


*Figure 8: DWGT Analysis Pie-Chart of Berlin.*

Research and innovation also play a vital role in advancing sustainable water practices. The **Kompetenzzentrum Wasser Berlin (KWB)** drives interdisciplinary research on water management and treatment technologies, ensuring that Berlin remains at the forefront of innovative solutions. By aligning its research priorities with emerging challenges, KWB provides actionable insights that inform policy and practice.

Financial instruments and funding programs further reinforce Berlin's commitment to NBS. The **GründachPLUS** initiative exemplifies this, offering grants to incentivize the greening of urban buildings through retrofitting and experimental projects. An innovative aspect of this instrument is the extra funding granted to those, that combine the greening of one's roof with the installation of solar panels – an example of multifunctional use of space in dense urban settings. This incentive-based approach complements broader strategies by promoting the adoption of green infrastructure.

Despite these robust frameworks and institutional efforts, significant challenges persist in scaling NBS. Policies like the Sponge City strategy and decentralized rainwater management provide clear direction both in law and already partially implemented in practice (see Decentralization in Figure 8). Yet, their full impact remains contingent on broader implementation. Surface decoupling requires substantial investment and coordination among administrative departments. Furthermore, while Berlin has made strides in public participation and stakeholder engagement, accelerating the adoption of NBS will demand continued collaboration and innovative approaches to funding, especially on private land. A great example for local initiatives taking up the strategic Sponge city approach is the **Wassertanke e.V.,** a neighborhood association installing free rain barrels with the financial help of the district authority and the knowledge support of the above-mentioned rainwater agency.

## 5.5 Sheffield

Most of the UK's water and sewerage systems are managed by private companies, often owned by multinational parent companies with responsibilities to shareholders first. The privatized water service regulation authority Ofwat sets regulations for water pricing. In contrast, flood risk management, sewage impact and diffuse pollution is the responsibility of UK Municipalities and the Environment Agency (EA). The National Framework for Water Management establishes water quality standards and regulates investments by water companies for infrastructure development. However, this framework lacks the flexibility and statutory funding mechanisms necessary to incentivize NBS or enforce green infrastructure requirements on private developments.

Flood risk management and diffuse pollution control are municipal responsibilities, with Sheffield City Council playing a critical role. National policies, such as the **2015 South Yorkshire Interim Local Guidance for Sustainable Drainage Systems,** promote NBS for urban drainage, such as swales, wetlands and bioretention areas. However, implementation remains inconsistent, as demonstrated by the limited application of NBS in new developments despite its inclusion in local policies like the Sheffield Development Framework and Strategic Flood Risk Assessment.
Sheffield's **Green Roof Policy**, once a leading initiative mandating green roofs on new builds in the city center, highlighted the potential for urban sustainability but was discontinued due to a lack of enforcement and continuity.

Unlike cities with normative master planning approaches, Sheffield's urban development is governed by the **Local Development Framework**, which provides a flexible structure but lacks a comprehensive master vision for integrated catchment-based water management (Ashley et al., 2012).
Additionally, during the planning and design stages, many SUDS techniques face resistance from advisory engineers due to uncertainties around long-term costs and performance risks. This hesitancy further limits NBS adoption, particularly in projects where developers are reluctant to absorb additional costs.

The **Gray to Green scheme**, which represents the largest SUDS retrofit in the UK, was a great example of collaborative governance efforts between local authorities, NGOs, universities.

Funded by European sources, this project transformed impermeable urban highways into multifunctional green spaces that manage stormwater, reduce CSOs, and enhance biodiversity. By diverting highway runoff directly to the River Don, the project mitigates flood risks while promoting urban aesthetics and ecological benefits. Led by Sheffield City Council, this project transformed extensive areas of impermeable surfaces into green spaces designed to manage stormwater.

Governance in Sheffield relies heavily on **public-private partnerships**, fostering collaboration between government, private entities, and NGOs. These decentralized mechanisms support NBS implementation but require stronger coordination for consistent outcomes (see Figure 9 Decentralization). A notable example is the **River Stewardship Company** (RSC) in Sheffield, an environmental service organization responsible for the maintenance of waterways and flood risk reduction. It is a private company offering contracting service for habitat creation, invasive species management, debris removal, etc., working as a contractor for the Environment Agency framework. This dependency on private companies has led to a loss of technical in-house expertise among key institutions in Sheffield, responsible for ecological aspects of NBS (T. Wild, personal communication, January 12, 2024). This may limit the integration of biodiversity aspects in government-led NBS projects.

While originally starting off as a watercourse maintenance company after the South Yorkshire floods, the RSC created the “Blue Loop”, a group encouraging local volunteers to assist in the improvement of local waterways. It also runs trainings to individuals through the “Riverlution” program, providing practical conservation skills. According to T. Wild Citizen engagement and citizen science projects in Sheffield are a notable enabler, such as the Don Catchment Rivers Trust Projects on wildlife and river monitoring. A robust network of volunteers and advocacy groups drives awareness and promotes green issues, offering opportunities for formalized engagement in planning and monitoring processes of NBS (T. Wild, personal communication, January 12, 2024). This grassroots energy could be further optimized through structured platforms or mechanisms for community participation.

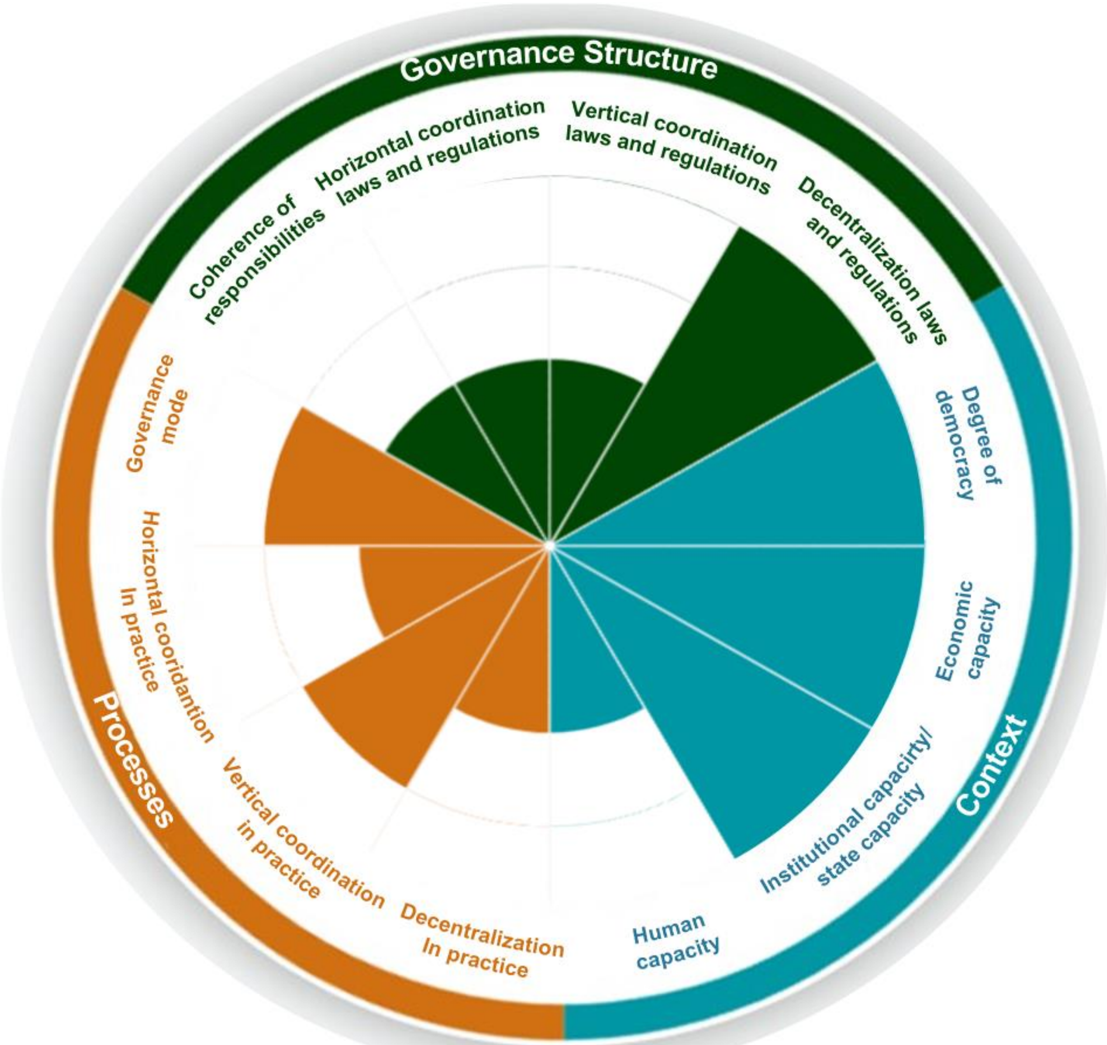


*Figure 9: DWGT Analysis Pie-Chart of Sheffield.*

# 6 Discussion

The results of the data analysis, both through the comparative data protocol and later via the DGWT have shown that each of the NICHES case study cities has their own individual configuration of actors, instruments, and policies when it comes to urban water governance and NBS implementation. While the *city-specific* weaknesses, gaps and opportunities in the current institutional and governance frameworks became apparent, it is important to discuss the differences and similarities between the cities, the *shared* elements, best practices or barriers, that allow the development of ’lessons-learned’ valuable for other cities. In the following, the governance systems of all five cities, as analysed through the water governance tool, will briefly be discussed in relation to one another. Afterwards, good practice examples of policies, instruments or institutions are highlighted, that serve as enablers and barriers of NBS implementation in the respective governance systems. At the end of the chapter, limitations of the applied methodology and the existing data will be briefly discussed.

## 6.1 Comparison of Governance Systems

Adding the scores of each DWGT pie chart gives a cumulative overview of each city's capacity within the three key dimensions of water governance: *Processes*, *Governance Structure* and *Context* (see Table 2).

*Table 2: Comparative overview of DWGT scoring of governance system per NICHES city. This table evaluates the governance systems in each NICHES city based on multiple criteria across three categories: Processes, Governance Structure, and Context. Each entry is scored out of a maximum (e.g., 3/4), indicating the city's performance in that specific criterion. Percentages show the overall score for each category. Own table.*

| | Processes | | | | | Governance Structure | | | | | Context | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Governance mode | Horizontal Coordination in practice | Vertical Coordination in practice | Decentralization in practice | **(Sum of 4 Variables)** | Coherence of responsibilities | Horizontal Coordination laws and regulations | Vertical Coordination laws and regulations | Decentralization laws and regulations | **(Sum of 4 Variables)** | Human Capacity | Institutional capacity / state capacity | Economic capacity | Degree of democracy | **(Sum of 4 Variables)** |
| **Barcelona** | 3/4 | 3/4 | 2/4 | 2/4 | 10/16 **(62,5%)** | 2/4 | 4/4 | 3/4 | 4/4 | 13/16 **(81%)** | 3/4 | 3/4 | 4/4 | 3/4 | 13/16 **(81%)** |
| **Boston** | 3/4 | 4/4 | 2/4 | 3/4 | 12/16 **(75%)** | 2/4 | 2/4 | 2/4 | 4/4 | 10/16 **(62,5%)** | 4/4 | 4/4 | 4/4 | 3/4 | 15/16 **(94%)** |
| **Rotterdam** | 4/4 | 3/4 | 3/4 | 4/4 | 14/16 **(87,5%)** | 3/4 | 3/4 | 4/4 | 4/4 | 14/16 **(87,5%)** | 4/4 | 4/4 | 4/4 | 4/4 | 16/16 **(100%)** |
| **Berlin** | 3/4 | 2/4 | 3/4 | 4/4 | 12/16 **(75%)** | 2/4 | 3/4 | 2/4 | 4/4 | 11/16 **(69%)** | 4/4 | 4/4 | 4/4 | 4/4 | 16/16 **(100%)** |
| **Sheffield** | 3/4 | 2/4 | 3/4 | 2/4 | 10/16 **(62,5%)** | 2/4 | 2/4 | 2/4 | 4/4 | 10/16 **(62,5%)** | 2/4 | 4/4 | 4/4 | 4/4 | 14/16 **(87,5%)** |

Rotterdam exhibits the strongest capacities in governance **Processes** with a score of 87.5%, demonstrating a highly structured approach to *Horizontal Coordination in practice* and *Vertical Coordination in practice* (3/4) and high levels of *Decentralization in practice* (4/4), which reflects effective multi-level collaboration and stakeholder engagement.

Boston and Berlin follow closely behind with scores of 75%, however they achieve that score through different variables. The water governance system in Berlin is characterized by strong *Decentralization in practice* (4/4) and *Vertical Coordination in practice* (3/4), the latter often forming the base for a successful decentralization of competences and processes. Boston, on the other hand, excels in *Horizontal Coordination in practice* (4/4), due to the efforts of the Office of Green Infrastructure.

Barcelona and Sheffield score the lowest in governance processes, each with 62.5%. Both cities exhibit limited *Decentralization in practice* (2/4), indicating that while decentralization efforts in laws and regulations may exist (see governance structure: *Decentralization laws and regulations* 4/4), their actual implementation is less effective.

*Horizontal Coordination* and *Vertical Coordination in practice* also remain moderate, possibly reflecting the challenges in integrating NBS and stormwater management across departments and throughout administrative scales.

The difference between the cities lies in the fact that while Sheffield also scores moderately in these categories 'in theory' (in laws and regulations), Barcelona has many regulations and mechanisms in play for coordination across sectors and scales (see governance structure: *Horizontal/Vertical Coordination laws and regulations* 4/4 and 3/4). What ultimately matters, however, is the actual implementation of those mechanisms and the political willingness among individuals to work together to benefit from a long-term sustainable implementation of NBS and to harness their multi-potential benefits, instead of choosing gray solutions to urban water management challenges, whose mitigation effects are often better known and whose design, implementation and monitoring less dependent on cross-sectoral cooperation.

In the dimension of **Governance Structure** Rotterdam leads again with 87.5%, highlighting its clear *Coherence of responsibilities* (3/4), robust coordination laws (*Horizontal/Vertical Coordination laws and regulations* 3/4 and 4/4), and strong decentralization framework (*Decentralization laws and regulations* 4/4). The city benefits from comprehensive and holistic water management policies, such as the Environmental Act (Omgevingswet), which integrates multiple governance levels into a single digital platform for decision-making. Barcelona follows with 81%, where aspects of coordination and decentralization are strongly incorporated into the legal and regulatory framework.

Boston and Sheffield score 62.5%, reflecting similar governance challenges. Their *Horizontal Coordination laws and regulations* (2/4) indicate weak interdepartmental collaboration as foreseen by local and state policies, and their rather low *Coherence of responsibilities* (2/4) suggests regulatory overlaps or ambiguities. All five cities score the lowest in this dimension, suggesting that unclear or incoherent responsibilities among institutions and actors is a shared barrier to NBS implementation but also presents a great opportunity for governance improvement.

The **Context** dimension is rated (rather) high for all, with their economic capacity scoring 4/4 across the board. These overall high scores can be associated with highly formalized water governance system, which, in turn, supports the implementation of formal governance instruments. Berlin and Rotterdam receive ratings of 100%, demonstrating the highest institutional, economic, and human capacity, alongside well-functioning democratic processes. These cities have strong institutions, well-funded governance systems, and participatory approaches, allowing for effective water governance and NBS integration.
Following them are Boston with 94%, Sheffield with 87.5%, and Barcelona with 81%, reflecting strong economic and institutional capacity but slightly lower overall robustness compared to Berlin and Rotterdam – for instance, due to a lack of human resources or limited stakeholder mobilization, that may limit NBS implementation, monitoring and policy enforcement.

The assessment of the *Context* is based on general datasets, such as BIP, Human Rights Index, Degree of Democracy on a national level, that the DWGT has already incorporated in the system and can not be altered by the person using the tool. As all five cities are examples of north-western, wealthy democracies. Therefore, the context is relatively similar to all five case studies and provides less insights into comparable characteristics of the governance frameworks of the cities. The assessment and evaluation of the categories *Processes* and *Governance Structure,* however, are based on the case specific data collected for this research and fed into the tool by the person using it. Therefore, the differences appearing from these scores provide much more valuable nuances of differences between the cities and show leverage points, where shared learning could develop. For this reason, these two categories should be the main focus when analyzing and comparing the cities.

Overall Rotterdam has the most mature governance system across all categories, excelling in *Processes* (87.5%), *Governance Structure* (87.5%), and *Context* (100%), with many innovative policy instruments already in place. Its high levels of vertical and horizontal coordination, strong legal frameworks, and institutional capacity make it a leading model for integrated urban water governance. Mechanisms for decentralization ensure that existing governance frameworks translate into effective local implementation. Strengthening legal mandates for interdepartmental collaboration can further enhance its governance efficiency.

## 6.2 Comparison of Enablers and Barriers

The comparative analysis of Rotterdam, Barcelona, Berlin, Sheffield, and Boston reveals a diverse range of enabling and hampering conditions for NBS implementation and CSO mitigation. While some cities excel in fostering collaborative governance and providing supportive frameworks, others face significant challenges related to institutional fragmentation, data availability, and stakeholder engagement. This discussion evaluates the enablers and barriers within the policy and governance contexts of these cities.

**Main Enablers**

***Citizen Engagement Through Collective Action***
Citizen engagement is a critical enabler for implementing NBS, as demonstrated for instance by innovative programs in Rotterdam and Berlin.

- In **Rotterdam**, the **Tegelwippen** initiative ("tile flipping") exemplifies how national competitions can integrate collective action into local adaptation strategies. This program encourages citizens to replace impervious surfaces with permeable ones, effectively engaging the community in climate adaptation efforts.
- Similarly, Berlin’s **Wassertanke initiative** demonstrates a bottom-up approach to citizen involvement. By providing free rain barrels for public spaces, the initiative fosters citizen participation in watering city trees. However, challenges remain in convincing property owners to take responsibility for maintenance, particularly in mixed-ownership scenarios. Information campaigns and support systems are critical to overcoming these obstacles.
- In contrast, **Boston’s Rain Barrel Program** adopts a top-down approach by distributing discounted or free rain barrels, primarily for private use. However, the lack of implementation support and evaluation data limits its effectiveness compared to Berlin’s more collaborative model.

***Cross-Sector Collaboration and Supportive Institutional Environment***
Effective NBS implementation requires collaboration across sectors and institutions.

- **Barcelona**, **Boston**, and **Berlin** provide exemplary models. The **Barcelona Department for Ecology, Urban Planning, and Mobility** enables cross-departmental collaboration, while Boston's **Office of Green Infrastructure (OGI)** ensures green infrastructure integration across municipal projects. Berlin's institutional framework, including the **Kompetenzzentrum Wasser Berlin (KWB)** and **Berliner Regenwasseragentur**, exemplifies how research and advisory bodies can support sustainable water management. These institutions provide legal advice, planning tools, and funding instruments while fostering stakeholder networks.
- Berlin's **Regenwasseragentur**, in particular, acts as an information hub and networking platform, facilitating dialogue between planners, property owners, and citizens. Such institutional environments create synergies that enhance the planning and implementation of NBS.

***Guidance and Vision Through Master Planning***

Comprehensive master planning provides the vision and strategic direction necessary for NBS and CSO mitigation.

- **Rotterdam's Weerwoord initiative**, part of the Netherlands' Environmental Act 2024 (**Omgevingswet**), exemplifies how national frameworks can guide local adaptation. The Environmental Act integrates all physical environment regulations into a single digital platform, streamlining urban planning processes.
- Berlin's **Wasserhaushaltsgesetz** and **the National Water Strategy** provide localized regulatory frameworks aligned with national goals. These master plans highlight the importance of aligning national and local strategies to provide clear priorities for urban water management.
- But also strategic vision, such as the Sponge City approach in Berlin, gives guiding directions for the formulation of future policy goals.

***Mix of Traditional and Innovative Approaches***

A combination of traditional funding mechanisms and innovative tools accelerates NBS adoption. Especially the use of digital tools seems to foster knowledge sharing and stakeholder engagement.

- Berlin's **GründachPLUS** funding scheme incentivizes green roofs and façades, integrating traditional financial subsidies with innovative approaches like the **Green Roof Lab** for high-quality projects.
- The Netherlands' **Digital Environmental Desk (Omgevingsloket)** combines traditional regulatory frameworks with user-friendly digital tools. It provides a comprehensive overview of environmental regulations, allowing stakeholders to easily navigate planning requirements.
- Berlin's **Digital Planning Table and Cost Calculator** showcases the role of technology in NBS planning. These tools facilitate data-driven decision-making by identifying areas with high potential for action, streamlining the design phase of green infrastructure projects.

**Main Barriers**

***Lack of Collaborative Governance***

- Institutional fragmentation and hierarchical municipal structures hinder NBS co-development in cities like **Sheffield**. The absence of a central coordination office leads to duplicated efforts and missed opportunities for integrating NBS into urban infrastructure projects.

***Knowledge and Data Challenges***

- Insufficient data and knowledge-sharing mechanisms impede the implementation of NBS, particularly in **Barcelona**, where quantifying context-specific NBS performance remains challenging. Developing standardized tools and metrics for assessing NBS effectiveness is essential for overcoming these barriers.

**Insufficient Policy Development and Enforcement**

- Delayed or inadequate policy implementation hampers progress in cities like **Boston**. For example, while Boston's regulations require stormwater mitigation plans for new projects, slow enforcement and administrative burdens discourage private sector engagement.

**Fragmented or Incomplete Policy Frameworks**

- The absence of holistic master planning is a significant barrier, particularly in **Sheffield**, where fragmented regulations fail to address long-term CSO management. In contrast, **Berlin's Schwammstadt (Sponge City)** vision provides a model for integrating water-sensitive urban design into comprehensive urban policies.

**Low Private Sector Engagement**

- High costs, administrative burdens, and limited incentives discourage private sector involvement. In **Sheffield**, developers are required to submit stormwater mitigation plans, yet the lack of streamlined processes and financial incentives reduces participation.

***Challenging Citizen Engagement***

- Citizen engagement requires time, communication, and alignment of diverse stakeholder interests. In **Barcelona**, the Superblocks initiative faced opposition from businesses concerned about reduced accessibility, highlighting the need for inclusive and participatory planning processes.

***Competition Over Urban Space and Resources***

- The repurposing of urban spaces for NBS competes with other vital services, such as housing and transportation. Underground infrastructure, such as water storage systems, also faces spatial and financial constraints, making retrofitting existing buildings particularly challenging.

## 6.3 Limitations of Methodology and Data

A significant limitation identified in the methodology used for this policy analysis was the inconsistency in the number of interviews conducted across different cities and the relatively small sample size. While multiple expert inputs were available in cities where stakeholder workshops have taken place, in others only one expert interview was done, due to time constraints. This discrepancy impacted on the weighting of information and the diversity of perspectives, particularly in representing the different social, technological, environmental dimensions of urban water management. To address this, extensive literature reviews supplemented cities where fewer interviews have been conducted, though future analyses should strive for uniform expert representation across all dimensions and a greater sample size.

Another methodological compromise was the decision to use the pre-existing *Diagnostic Water Governance Tool*. The tool's focus on broader water governance missed specific governance aspects pertinent to NBS implementation and CSO events. While the tool offers valuable comparative insights, its utility is primarily focused on two of the three dimensions—governance structure and processes—leaving the contextual differences between cities underexplored in this analysis. Future research would benefit from conducting a more detailed context analysis at the city level, as the factors currently automatically considered for contextual assessment (e.g., GDP, Level of Democracy) are applicable at national level. The authors had no influence on the algorithm and the empirical database underlying the DWGT, therefore no 'calibration' of the tool was done, and potentially existing methodological flaws of the tool could not be double-checked.

A further limitation stemmed from the subjective nature of filling out the governance tool, as it was completed by the authors based on expert judgment. This approach introduced potential biases and affected the reproducibility of the findings. The results were discussed within the consortium and verified by city representatives to mitigate this bias. However, the involvement of local governance experts in reviewing the tool's outcomes could have further enhanced the analysis.

# 7 Conclusion

In addressing the challenge of urban stormwater management exacerbated by climate change, this study delved into the potential of implementing NBS within diverse urban governance frameworks. The analysis, grounded in the SETS framework, has emphasized that while NBS hold promise for enhancing urban resilience and providing co-benefits like biodiversity and quality of life, their integration demands robust supportive governance and policy structures. The insights drawn from the five cities—Rotterdam, Barcelona, Berlin, Sheffield, and Boston—illustrate varied success levels in adopting NBS, primarily influenced by the existing governance structures and policy frameworks.

The research revealed that collaborative governance models are essential for the effective implementation of NBS, with successful cases in Rotterdam and Berlin showcasing the benefits of involving a range of stakeholders from different sectors and levels of administration in urban planning processes. These models not only support the physical implementation of green infrastructures but also foster policy frameworks that facilitate sustainable urban water management.

Furthermore, the analysis underscores the importance of adapting policy and governance structures to local contexts to maximize the effectiveness of NBS. The insights from this study can serve as a guide for policymakers and urban planners, advocating for integrated approaches that include NBS in urban water management strategies

The enabling and hampering conditions identified across the cities illustrate the complexities of implementing NBS for CSO mitigation. Collaborative governance, citizen engagement, and innovative tools emerge as critical enablers, while institutional fragmentation, policy gaps, and competing priorities pose significant challenges. Addressing these barriers will require integrated approaches, robust data systems, and inclusive engagement strategies to unlock the full potential of NBS in urban water management.

In conclusion, this research contributes to the broader discourse on urban sustainability by highlighting supportive and hampering aspects of governance and multi-stakeholder involvement and offering viable solutions to many of the challenges facing contemporary urban water management. By building on the lessons learned and addressing the limitations noted, future studies can more effectively support the crafting of policies that not only mitigate the impacts of CSOs but also harness the full potential of NBS to foster resilient and sustainable urban environments.

# 8 Recommendations for Decision Makers

Drawing from the comparative policy analysis of five major NICHES cities, the following reccomendations for policy makers and practitioners apply, for the development of a governnace setting that is favourable for the implementation of NBS and the mitigation of CSO events:

**Promote integrated governance models**

- Foster vertical coordination mechanisms that align municipal, regional, and national policies to create a cohesive governance framework.
- Draw inspiration from Rotterdam's collaborative platforms, such as the Waterkracht Alliantie, to harmonize objectives across governance levels and improve water management efficiency.

**Enhance public participation and co-creation**

- Engage local communities, businesses, and NGOs in the design, implementation, and monitoring of NBS.
- Adopt participatory governance approaches, such as Barcelona's PLARHAB stakeholder consultations in policy drafting, to build resilient and multifunctional infrastructures that address both local and systemic challenges.

**Expand Innovative not bureaucratic funding mechanisms for NBS**

- Establish dedicated funding streams that provide consistent financial support for NBS initiatives.
- Leverage public-private partnerships to pool resources and share risks, ensuring long-term sustainability of NBS beyond traditional grey infrastructure projects.

**Foster private sector engagement and incentives for NBS**

- Implement incentive programs for NBS adoption on private land, taking cues from Boston's approach to stormwater management through compliance-based permits and subsidies.
- Develop support mechanisms for private landowners, such as grants, tax benefits, or technical assistance, to encourage widespread integration of NBS in urban settings.

**Address institutional silos**

- Create interdepartmental task forces to ensure horizontal coordination and effective cross-sector collaboration.
- Follow the examples of Berlin and Barcelona, where collaborative platforms and cross-departmental working groups have successfully mitigated institutional fragmentation in urban planning and water governance.

**Leverage digital tools for NBS knowledge management and facilitation**

- Utilize digital platforms to enhance knowledge management, raise awareness, and facilitate planning for NBS implementation.
- Develop user-friendly tools for private entities, enabling them to easily access regulatory information, assess feasibility, and integrate NBS into their projects such as Rotterdam's Environmental Desk.
- Encourage innovation in digital mapping and visualization tools to support participatory decision-making and improve stakeholder communication.

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