Water, Cities & Society

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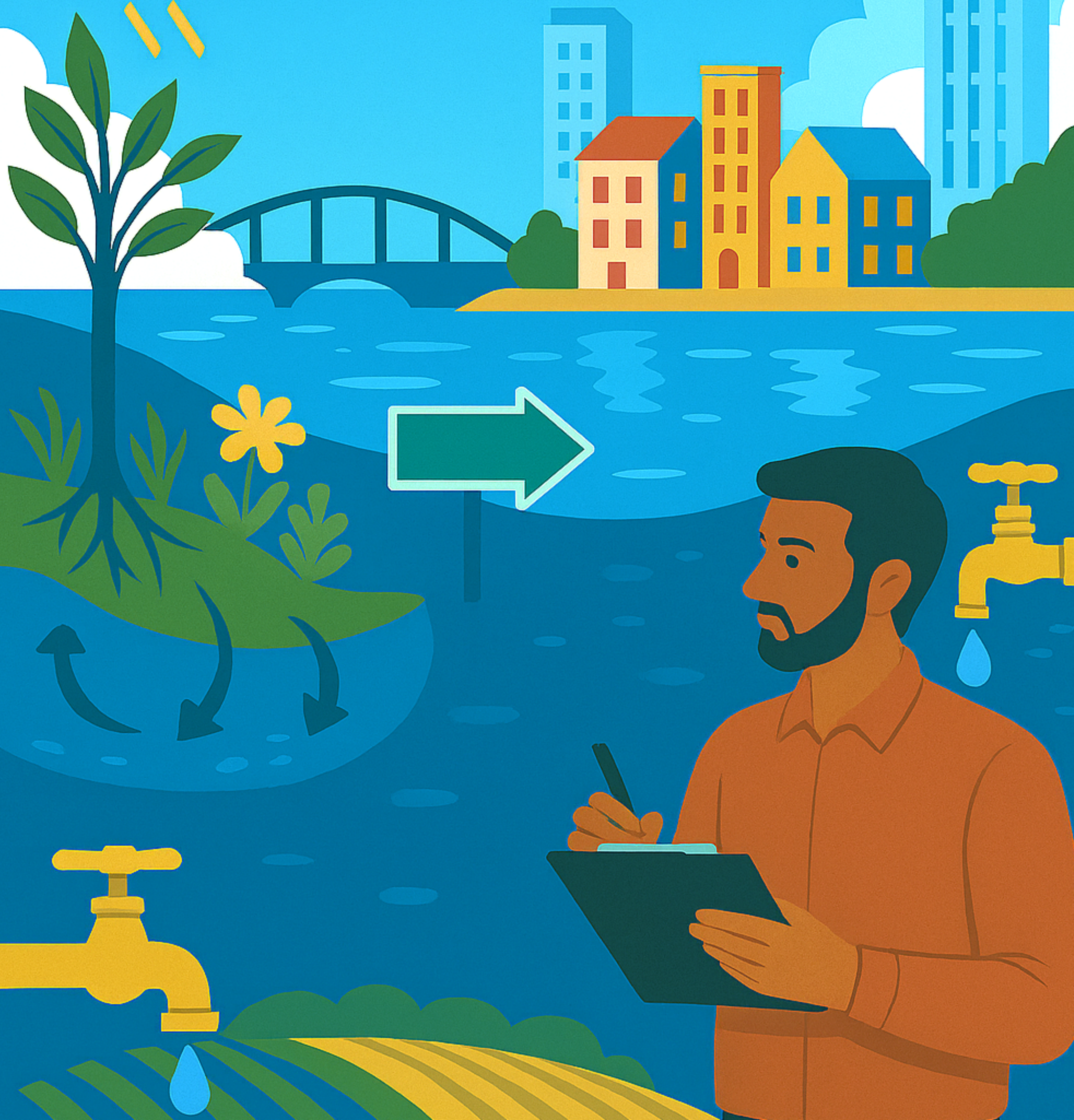

Installation of Rain Gardens in Shibuya and Their Sustainable Maintenance System

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Abstract

Rain gardens are depressions that temporarily store rainwater runoff so it permeates underground slowly. Contrasting to “gray infrastructure,” such as asphalt, rain gardens are a representative example of “green infrastructure”, prompting a healthy water cycle through groundwater recharge. Shibuya is located on the valley floor and thus has a high risk of pluvial flooding [1]. The installation of rain gardens will alleviate the strain of inflow on the sewerage system, effectively suppressing flood damage.

This report looks into the implementation method of rain gardens that best matches Shibuya’s urban characteristics based on precedents in other places. Furthermore, to ensure sustainability after the installation of rain gardens, the most effective maintenance system model will be explored by comparing and evaluating the merits and demerits of each possible operating body. Placing the right man in the right place is key to achieving a sustainable maintenance system of rain gardens. By building a system that realizes the ideal cooperation between the public and private through referencing developed cases from abroad, improvement of the urban flooding issue in Shibuya is expected. Ultimately, application of this model to other cities with characteristics similar to Shibuya could contribute to increased resilience to pluvial flooding worldwide.

Keywords

rain garden, green infrastructure, pluvial flooding, sustainability, torrential rain

1 Introduction

1.1 Research Background

In recent years, due to the effects of climate change, sudden downpours have become particularly frequent in Japan, especially during the summer [1]. In the Tokyo metropolitan area, the urban climate makes it especially prone to sudden, intense rainfall. For example. in Shibuya City where our school is located, approximately 100 millimeters of torrential rain fell in the hour leading up to 6:50 p.m. on July 10, 2025, prompting the issuance of a “Record-breaking Short-Term Heavy Rain Advisory.” As can be seen from the kanji character for “valley (谷)” in Shibuya’s name contrasted the names of surrounding places such as Aoyama, Daikanyama, and Dogenzaka, which have kanji characters for “mountain (山)” and “hill (坂)”, the area has a bowl-shaped topography.

Figure 1: Map of Shibuya [2]

It lies at a lower elevation than the surrounding areas, making it prone to the inflow of surface rainwater. Furthermore, in major Japanese cities, including Shibuya, most of the ground is covered in concrete, making it difficult for rainwater to seep into the ground as it would naturally. In fact, it is not uncommon for the massive amounts of rainwater that gather in Shibuya to fail to filtrate the ground, leading to flooding in the surrounding areas. Additionally, nearly all of Tokyo’s sewer systems use a combined sewer system, which collects both rainwater and sewage in the same pipes. While combined sewer systems can be constructed quickly and inexpensively, during heavy rains, the pipes become filled with rainwater, preventing sewage from flowing properly and causing it to overflow. In Shibuya, where these factors converge, urban flooding is likely to occur during sudden, intense downpours.

To address this issue, the Shibuya Station East Exit Stormwater Retention Facility began operations on August 31, 2020. Located approximately 25 meters below ground level beneath the Shibuya Station East Exit Plaza, this large-scale structure measures approximately 45 meters north-south and 22 meters east-west. It collects stormwater during heavy rainfall exceeding 50 mm per hour and discharges it into the existing main sewer lines via pumps once the weather improves. However, this facility has its limits and can only handle rainfall of up to 75 mm per hour [3]. The frequency of torrential rains over 80 mm has doubled since the 1980s, and the existing solutions alone are insufficient to address the heavy rains anticipated in the future [4].

Figure 2: History of flooding in Shibuya [4]

Therefore, this paper examines rain gardens as a new flood control measure in Shibuya. A rain garden is a planted space designed to collect and temporarily store surface rainwater before allowing it to filtrate into the ground; it is a prime example of “green infrastructure” that promotes a healthy water cycle through groundwater recharge, in contrast to “gray infrastructure” such as asphalt. In rain gardens located alongside roads, rainwater is collected by replacing some of the curbstones with perforated ones or by creating indentations in them [5]. The collected rainwater is absorbed by the sandy soil layer above and the stone layer below, seeping deep into the ground. Some of the water is absorbed by plants and released into the air as water vapor through transpiration. The remaining rainwater evaporates after the rain stops. If the amount of rainwater exceeds the rain garden’s capacity, the excess flows into the storm drain as usual [6]. In addition to this role in reducing stormwater runoff, rain gardens offer benefits in various other areas, such as improving water quality, enhancing landscaping and greenery, mitigating the urban heat island effect, and contributing to biodiversity. The differences between rain gardens and other forms of green infrastructure include the fact that rain gardens are relatively small in scale and are installed in highly visible locations so that they can facilitate environmental education. These characteristics make them particularly effective in a bustling city like Shibuya, where flooding occurs frequently and available land is scarce.

Conducting an interview with the staff of Shibuya Ward, it was found that the ward has not yet established any rain gardens, and no clear information regarding the establishment of rain gardens on private property was found. This is because Shibuya Ward, despite acknowledging the existence of rain gardens, does not have enough knowledge on them. From the impression that such gardens require a lot of area and cost, Shibuya has not considered implementing rain gardens.

1.2 Analysis of Precedent Cases

Below are some examples of rain gardens in use. Major examples of cities around the world where rain gardens have been implemented include A. Kyoto, B. New York, C. Portland, and D. Michigan.

A) Kyoto

Since traditional gardens that have long been created at temples and shrines—such as Shōkoku-ji— had rain garden-like features, rain gardens were introduced by leveraging the traditional landscaping techniques that have preserved this garden culture. As of May 2026, a total of 18 rain gardens have been installed at locations such as intersections and in front of train stations; details regarding their locations can be found on the rain garden location map published by the City of Kyoto [7]. Post-installation management of the rain gardens is carried out by citizen volunteers through the "Kyoto City Street Tree Supporter Program [5]."

B) **New York City**

As part of a national initiative to improve water quality, the DEP has led efforts to install rain gardens along roadsides and other locations, with the number of such sites now numbering in the thousands. In the United States, the original purpose of green infrastructure was "outflow management"—protecting the environment from human activities—but following the arrival of major hurricanes in 2012, it came to include the role of "inflow management"—protecting human activities from the environment. The need for rain garden management stems from several factors, such as combined sewer systems that navigate sewage to flow into rivers during heavy rainfall, and coastal areas experiencing flooding due to storm surges, high tides, and strong winds caused by hurricanes. These issues—combined sewer systems, a high risk of flooding, and the city's status as a major metropolis—are shared with Tokyo as well [8]. Details on the locations of New York's rain gardens can be found on the Interactive Map of Green Infrastructure Projects [9]. Additionally, many rain gardens in New York are equipped with signage, providing passersby with an opportunity to learn about rain gardens and green infrastructure. Post-installation management is often handled by volunteers, residents, and companies.

C) **Portland**

Against a backdrop of river pollution caused by industrialization, the designation of salmon and rainbow trout as endangered species, and calls from residents for regulations on sewage overflow from combined sewer systems, the development of rain gardens has progressed in Portland, resulting in more than 3,600 rain gardens [10]. In Portland, under a system called "stewardship," residents have registered for the program to maintain green streets—including rain gardens—by removing trash and fallen leaves and watering the plants [11]. The government is also putting systems in place to support residents' activities, such as posting maintenance instructions on its website.

D) **Michigan**

The University of Michigan-Dearborn has installed rain gardens on its campus, and Michigan State University is encouraging residents across the state to adopt them as well [12, 13]. In addition to filtering stormwater and improving water quality, the University of Michigan's rain gardens aim to promote biodiversity by planting native plants. Michigan's native plants help attract native wildlife and have been certified for monarch conservation. The state university has also published information on its website regarding the installation of rain gardens at home—including recommended plants and simple maintenance procedures—making it accessible to everyone. Additionally, around the southern area of Lake Michigan, organizations such as Lawn to Lake and Purdue University are leading efforts to install rain gardens as a measure against heavy rainfall. They are actively promoting rain garden installation not only on state-owned land but also among residents living in the surrounding areas.

Based on the successful early implementation cases of rain gardens described in sections A through D, this study examines the process and challenges involved in introducing rain gardens in Shibuya Ward, as well as the methods and entities responsible for post-installation maintenance. The goal is to devise the optimal implementation process for Shibuya.

2 Literature Review

Although there are many research papers on green infrastructure, few focus specifically on rain gardens, and even fewer consider their maintenance.

Portland serves as one example of a leading case; the methods of utilizing and maintaining rain gardens in this city are described in detail in Fukuoka & Kato, 2015 [14]. This study presents a perspective on green infrastructure that differs from that in Japan, demonstrating the versatility of green infrastructure. Furthermore, it presents a detailed survey of rain gardens in Portland, including information on owners and users, organized in tabular form.

For the selection of stakeholders, we referred to Fukuoka & Kato, 2019 [15]. This paper explains a strategy for promoting green infrastructure through collaboration among the 3Ps (People, Public, Private). By highlighting not only the potential for multiple stakeholders to be involved in green infrastructure but also the importance of their collaboration, this study is considered to make a significant contribution to research on the maintenance and management of rain gardens.

Maeda et al. 2023 [5] conducted a comprehensive study in the field of rain garden maintenance, an area where research examples are particularly scarce. Using Kyoto City as a case study, they clarified the continuous maintenance process following the construction of rain gardens. Specifically, they analyzed the current status of installed rain gardens through interviews with Kyoto City officials and on-site inspections. Furthermore, Maeda subsequently proposed student organizations as the entity responsible for maintenance when introducing rain gardens in Kobe City [16]. This revealed the possibility of academic organizations taking on the role of a maintenance entity. As Japanese academic papers focusing primarily on rain garden maintenance, these studies are highly significant for considering potential management entities [17].

A detailed checklist has been developed for analyzing the maintenance status of rain gardens. The “Performance Assessment of Rain Gardens” created by the American Water Resources Association logically explains detailed verification methods, covering not only water flow and the presence of pools within the rain garden but also ways to evaluate vegetation.

Since our research focused more on actual implementation cases and site visits to rain gardens than on the analysis of prior studies, many of the referenced papers include analyses of implementation cases or guides for conducting site visits. Unlike manuals or construction, few rain gardens explicitly state the responsible entity for maintenance; therefore, papers researching this aspect are crucial. On the other hand, there is a shortage of research materials regarding the maintenance and management of green infrastructure. To conduct more detailed research on maintenance and management, a comprehensive review of existing cases that clearly specify the responsible entity is required.

3 Body

This study assumes the introduction of rain gardens in Shibuya Ward, Tokyo. Given the need for disaster prevention, implementation should take place as soon as possible. For site selection, we will use the criteria for determining the feasibility of green infrastructure installation published by Kyoto City [11]. The four criteria for installation are: land permeability, flood history, level of activity, and the ability of residents to maintain and manage the site. Shibuya is home to not only residents but also many tourists, and it is judged that the ward has a sufficient level of activity. Regarding local resident participation, the “Shibuya Ward Basic Green Plan” indicates that approximately 60% of residents are currently engaged in greening activities or plan to do so, demonstrating a high level of interest in greening their homes and participating in local greening initiatives [18]. Therefore, this paper selects sites that meet the criteria of high infiltration capacity and no history of flooding, as shown on the map below. The rain gardens addressed in this study are not based on existing examples in Japan but rather referencing to overseas case studies. Instead of raising the ground level around the rain garden, the rain garden itself is designed to be lower than the surrounding ground to ensure that rainwater flows in properly. In implementing such a rain garden, the entities responsible for creating the manual, construction, and maintenance become critical issues to prevent a decline in functionality after installation.

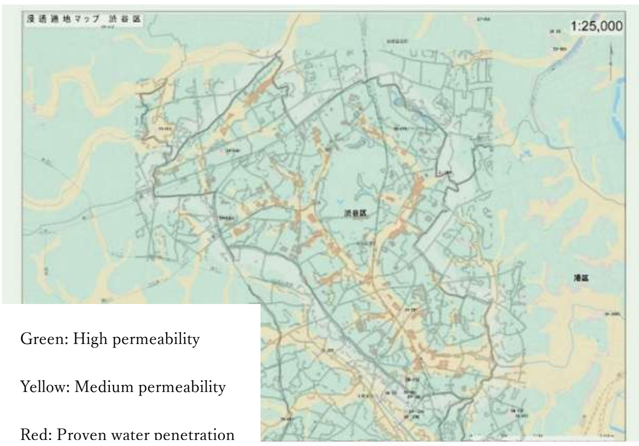

Figure 3: Suitable locations for rain gardens in Shibuya [19, 4]

3.1 Organization of Operating Bodies

Referencing the primary entities responsible for manual preparation, construction, and maintenance identified in the previous chapter's review of prior cases, we will now organize the entities to be compared in this study. In Kyoto City, the city commissions landscaping contractors to construct rain gardens. In addition, citizen volunteers known as "Street Tree Supporters" perform routine maintenance tasks such as cleaning, while the road authority handles regular, year-round management. In New York, the New York City Department of Environmental Protection (DEP) constructs and maintains rain gardens [19]. Furthermore, a system has been established through stewardship that allows local residents to assist with rain garden maintenance. In Portland, during the implementation phase, four departments are responsible: the Watershed Management Division and the Sustainable Stormwater Management Division within the Watershed Services Department of the Bureau of the Environment, the Stormwater System Revitalization Program within the Engineering Department, and the Public Relations Section within the General Affairs Department [14]. Management is carried out by 12 staff members from three departments—the Sustainable Stormwater Management Division of the Watershed Services Department, the Design Division of the Engineering Department, and the Operations Management Division of the Sewer Department—along with three specialized contractors, regardless of whether the facility is public or private. In some cases, local residents also take on the responsibility. In Michigan, although it is not explicitly stated, since the rain gardens are located on university campuses, it is assumed that the university's Environmental Interpretive Center is responsible for their maintenance. Regarding rain gardens around Lake Michigan, not only are university and private organizations taking the lead in their maintenance, but there are also campaigns encouraging volunteer participation for it. Based on this, this study evaluates and compares five entities—the country, local governments, private enterprises, academic organizations, and citizen volunteers—from the three perspectives of manual creation, construction, and management. It then examines the optimal entity for each perspective in Shibuya, as well as the optimal methods of collaboration among these entities. Furthermore, Shibuya City is located within the 23 wards of Tokyo, presenting a unique case in which there are two local governments: the Tokyo Metropolitan Government and Shibuya City. Therefore, this paper examines both the Tokyo Metropolitan Government and Shibuya City as local government entities.

3.2 Operating Body for Manual Creation

The operating body responsible for creating the manual must have the clout to ensure the manual's public accessibility and reliability for citizens, possess knowledge of rain gardens, and be capable of updating the manual. We will consider the most suitable entity that meets these criteria.

3.2.1 Country

The national government is the most influential of these potential entities. The documents it produces are not necessarily limited to specific guidelines for constructing rain gardens; they often take the form of large-scale planning documents outlining how much and how the nation as a whole should implement green infrastructure in the future. Since this is an entity that affects the entire population, creating and distributing a manual—regardless of whether it is implemented in Shibuya Ward specifically—is expected to increase the number of rain gardens installed throughout Japan. On the other hand, disadvantages include the fact that the scale is too large, leading to slow progress, and that reaching a single decision requires significant time and personnel. While the national government generally possesses resources, its priorities may not align with rain gardens, creating hurdles in terms of enthusiasm and dedication to this topic. As an actual precedent, the National Institute for Land and Infrastructure Management (NILIM) under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has created the "Guide to Green Infrastructure Implementation in Road Spaces," available online [11]. Although it is not a manual specifically for rain gardens, it provides detailed explanations of factors local governments should consider when introducing green infrastructure into road spaces, methods for collaborating with stakeholders, and maintenance procedures. While it is very useful for organizations already considering the introduction of green infrastructure, it rarely reaches companies or the public unfamiliar with the concept, so it is unlikely to serve as a catalyst for environmental education or volunteer activities.

Furthermore, the MLIT is the primary government agency promoting green infrastructure in Japan. The "Green Infrastructure Promotion Strategy 2030" is the most recent comprehensive planning document; it "outlines the new definition, effects, and characteristics of green infrastructure, as well as the vision for society we aim to achieve through its utilization. It also aims to realize a 'society where the use of green infrastructure is the norm' and positions MLIT's initiatives in a comprehensive and systematic manner [20]." Regarding rain gardens, the document notes that greening technologies are currently insufficient, and their widespread adoption and implementation are necessary. Therefore, it stipulates the accumulation of technical knowledge and case studies in this field leading up to 2030, as well as the collection and dissemination of information on rain garden implementation cases by local governments, civic groups, and other entities. Similarly, the Ministry of Land, Infrastructure, Transport and Tourism's "Encouraging Green Infrastructure Projects and Investments: Toward Promoting Investment in Urban Development and Community Planning Through the Visualization of Economic Benefits" demonstrates the benefits and effectiveness of implementing green infrastructure through case studies, thereby fostering understanding and encouraging consideration of its adoption [21]. For example, regarding the Shijo Rain Garden Development Project in Kyoto, the document states that "economic benefits in the form of reduced flood risk were achieved." Furthermore, in its "Green Infrastructure Practice Guide," the MLIT states, "In urban areas characterized by high-density and mixed-use land development, the creation and utilization of green spaces and waterfronts can comprehensively address social challenges such as climate change adaptation, the creation of 'comfortable, walkable' city centers, and the conservation of biodiversity." In this way, the government is formulating an overall strategy for green infrastructure in future Japan [22]. Additionally, the "Compendium of Support Programs Related to Green Infrastructure" summarizes support provided by the MLIT, the Ministry of Agriculture, Forestry and Fisheries, the Ministry of the Environment, and other agencies for green infrastructure initiatives [23]. In the case of Shibuya Ward, the compendium lists programs such as the Comprehensive Social Infrastructure Development Grant/Disaster Prevention and Safety Grant—New Generation Sewerage Support Program, which supports individual initiatives within Shibuya Ward, and the Pioneering Green Infrastructure Model Formation Support Program, which supports initiatives undertaken by Shibuya Ward.

In terms of international examples, the U.S. Environmental Protection Agency has published a comprehensive manual on green infrastructure, including one for local governments [24]. This portal site compiles not only manuals created by the EPA but also those developed by local governments. In Singapore, the Public Utilities Board has taken the lead in publishing the ABC Waters Design Guidelines, a set of guidelines designed to promote comprehensive green infrastructure on a national scale. The guidelines include project planning, information on green infrastructure, and a certification system for green infrastructure projects undertaken by other entities [15].

When a manual is developed by a government agency, since government officials are not experts in rain gardens, close collaboration with knowledgeable entities such as academic organizations allows them to acquire practical technical knowledge and produce high-quality materials that can be widely disseminated to the public. Currently, the national government has not published any materials that provide the kind of information readers can use to immediately start building rain gardens; instead, rain gardens are often merely mentioned as a major component within documents covering green infrastructure in general. Japan began adopting green infrastructure later than Western countries, and considering that the "Green Infrastructure Promotion Strategy 2030" was only released this past January, the government has not yet made it a priority to issue nationwide guidelines standardizing the basics of rain garden construction. Therefore, when the national government issues guidelines to construction entities nationwide—including those in Shibuya Ward—having influence, such as the citizens' accessibility to and trust in the manual becomes crucial. While the fact that it comes from the government tends to foster trust, pinpointing it among the vast number of available materials is difficult, so its accessibility cannot be said to be high. Furthermore, regarding the ability to update the manual, the national government's operations are inevitably large-scale, so updates are not swift. Consequently, while there is a possibility that the national government decides to create and publish its own manual in the future if it deems it necessary, at this stage, it is more realistic for other entities to create more detailed manuals in line with the broad guidelines set by the national government, as this approach is more realistic and offers multiple advantages.

3.2.2 Local Governments

3.2.2.1 Tokyo

The Tokyo Metropolitan Government's Bureau of Urban Development has created and published online a document titled "Rainwater Green Infrastructure CONCEPT BOOK [25]." After explaining the mechanisms of green infrastructure and the water cycle, the book compiles and introduces examples of green infrastructure already implemented in Tokyo. While it touches on the effects and evaluation of green infrastructure, as well as a simple overview of how to create rain gardens, it is not as detailed as a technical report; rather, it is intended as an introductory guide for the general public. This is the most comprehensive and concrete resource on rain gardens published by the Tokyo Metropolitan Government. In urban planning documents issued by the Tokyo Metropolitan Government in 2026, the term "green infrastructure" nor rain gardens appear in "Grand Design for Urban Development," whereas "Tokyo 2050 Strategy: Making Tokyo Even Better" presents both green infrastructure and rain gardens as initiatives that should be promoted [26]. Furthermore, the Metropolitan Government's Basic Policy on Heavy Rain Countermeasures recommends the construction of green infrastructure, including rain gardens [27]. However, the Metropolitan Government does not have any manuals, guidelines, or websites that specifically explain the construction or maintenance of rain gardens.

As for overseas examples, The Vermont Rain Garden Manual is a highly useful reference [28]. Published in 2008, this manual provides a highly detailed overview—complete with numerous diagrams and photographs—covering everything from the fundamentals of rain gardens to site selection, design, construction, and maintenance. It was developed specifically to address Vermont's unique state laws, climate, and vegetation, and it is likely that the Tokyo Metropolitan Government would aim to create a manual along these lines. By collaborating with nearby universities and other institutions from the planning stage, the manual ensures the accuracy of its information. As expected, its success was due to its level of specificity; in fact, a revised second edition was released in 2009 with updated information, and other local organizations have used it as a basis to create manuals tailored to the specific characteristics of their own regions, such as "The Southern Lake Michigan Rain Garden Manual" [29].

In March 2026, through an introduction by Professor Takanori Fukuoka of the Department of Landscape Science, School of Environmental Policy at Tokyo University of Agriculture, we conducted an interview with staff from the Road Maintenance Section of the Road Division within the Civil Engineering Department. During the interview, it was noted that because Shibuya Ward holds a unique position as a local government—being one of Tokyo's 23 special wards—it will be able to proceed with rain garden construction by complying with the metropolitan government's policy once a specific manual is issued by the Tokyo Metropolitan Government. Furthermore, as seen in the Vermont case, when one local government sets a precedent, it tends to spread to other local governments. As the only metropolitan government and the nation's capital, the Tokyo Metropolitan Government is in a position to take the lead in creating specific manuals for local governments.

If the Metropolitan Government were to create such a manual, its credibility and enforcement capacity within the 23 wards would be very high. As with Shibuya Ward's future release of a manual, it is expected that such a manual would be posted on the Tokyo Metropolitan Government's official website. Since Tokyo residents, including those in Shibuya Ward, use the Metropolitan Government's website on a daily basis, accessibility is relatively high, and as materials published by the government undergo a review process to ensure accuracy before release, it is believed that comprehensive and accurate information can be provided. On the other hand, since the Metropolitan Government does not yet possess a high level of expertise regarding green infrastructure either, collaboration with experts is essential. Given that the highly comprehensive "Rainwater Green Infrastructure Concept Book" is updated significantly on an annual basis, and that other materials on green infrastructure are also increasing in number, the city's current enthusiasm for rain-related green infrastructure—including rain gardens—is very high; therefore, its capacity for future updates is expected to be more than adequate.

3.2.2.2 Shibuya Ward

In Shibuya Ward, the Shibuya Ward Basic Green Plan outlines greening policies, including green infrastructure [18]. Among the 23 wards, Setagaya Ward has published the Setagaya Green Infrastructure Guidelines [30]. This guideline is divided into a Main Section, a Practical Section, and a Reference Section. Each section consists of an explanation of the concepts behind green infrastructure initiatives, an introduction to their actual effects and the efforts of participating organizations, and a description of implementation examples and organizational structures. Among green infrastructure guidelines at the municipal level in Japan, this is considered particularly detailed. In addition, Kyoto City, which has installed 18 rain gardens throughout the city, has chosen not to create specific guidelines, instead relying on certified volunteers to carry out activities on their own initiative. As such, while a certain number of manuals and guidelines on green infrastructure exist in Japan, their total number is limited, and there are no manuals specifically focused on a single type of green infrastructure—such as rain gardens—that citizens can easily engage with.

Meanwhile, in overseas—for example, in New York—the "Rain Garden Stewardship Program Maintenance Manual" has been published [31]. This is a maintenance manual for citizen volunteers participating in the stewardship program, and it provides detailed and easy-to-understand information, including equipment checklists, photographs, diagrams, step-by-step instructions, and troubleshooting tips. In Portland, the Environmental Services department has published a manual titled "with Rain Gardens [32]." This manual focuses on rain gardens at private residences and, while it includes specific numerical values for maintenance methods, it places particular emphasis on the design and installation of rain gardens, explaining these concepts clearly with diagrams and specific numbers. For Green Street Steward, the city has published the "Green Street Steward Maintenance Guide," which provides detailed explanations of maintenance methods with photographs [33]. However, since the New York City Rain Garden Stewardship Program Maintenance Manual was published in March 2019, the Portland "With Rain Gardens" manual in August 2021, and the Green Street Steward Maintenance Guide was last updated in November 2017 with no subsequent revisions, it can be said that the ability to update manuals in New York City and Portland is low.

If Shibuya Ward were to publish a manual on rain gardens, it would likely be posted on the ward's official website. Since residents frequently use the ward's website for other purposes, such as handling various administrative procedures and checking lifestyle information, its accessibility can be considered relatively high. Furthermore, government-published materials are reviewed for accuracy before being released, ensuring that they provide reliable information that is not biased toward any particular viewpoint.

On the other hand, an interview conducted with the staff of Shibuya Ward revealed that, as of now, the ward currently lacks a department or staff specializing in rain gardens. Since there are no precedents for the development and management of rain gardens, the ward alone faces limitations in creating a manual that incorporates specialized knowledge on the subject; therefore, cooperation with other entities possessing such expertise is essential. Furthermore, as evidenced by instances in New York City and Portland where manual updates have been inadequate, the need for careful procedures to ensure the accuracy of information in administrative documents means that the frequency of manual updates cannot be described as high.

3.2.3 Private Enterprises

In Japan, while there are few instances of private companies independently creating and publishing manuals, there are cases where they provide expertise in collaboration with local governments and public works projects. This is supported by the observation that "collaboration among diverse stakeholders, including private companies, is crucial" for the promotion of green infrastructure [20].

In Tokyo and its suburbs, companies specializing in urban greening and stormwater management are involved in the design and construction of stormwater infiltration facilities and bioswales, and the knowledge gained through these processes is being compiled into technical documents. In Shibuya Ward, elements of stormwater management and green infrastructure are being incorporated into redevelopment projects led by private companies. For example, at Shibuya Stream, urban development is being carried out by Tokyu Corporation in conjunction with the revitalization of the Shibuya River, with the aim of "forming a network of water and greenery to improve the urban environment" [34].

Such initiatives share a common philosophy with rain gardens, which involve temporarily storing and infiltrating stormwater within the urban space rather than simply draining it away. Furthermore, at Shibuya Cast, designs that take water circulation into account have been incorporated into the green spaces and open areas on the premises, demonstrating the implementation of environmentally conscious infrastructure within a private-sector development. The companies' design intent and structure are sometimes explained in brochures or on websites; however, this information is primarily aimed at clients and experts and is not sufficiently systematized to serve as a manual for citizens to implement green infrastructure at home.

There are many more concrete examples in the United States. In Portland, private landscape firms collaborate with the city's green infrastructure promotion program to provide a "Rain Garden Installation Guide" that has detailed, illustrated explanations of how to install and manage rain gardens for residents. Since these materials are based on the actual experience of companies that perform the work, therefore, they are highly practical [35, 36]. In Philadelphia's "Green City, Clean Waters" program, "a 25-year plan to reduce the volume of stormwater entering combined sewers using green infrastructure", private companies are not only involved in design and construction but also in the creation of guidelines for residents [37]. Materials related to this program provide step-by-step instructions for installing rain gardens on a residential scale, including specific dimensions, estimated costs, and the time required for construction. This information helps lower the barriers for citizens when considering implementation.

Private companies have a significant advantage in that they are directly involved in practical operations such as design, construction, and maintenance, enabling them to create practical, field-based manuals. In particular, they have accumulated knowledge regarding soil conditions and drainage structures encountered during construction, which is extremely useful for citizens when actually installing rain gardens. Furthermore, since they promote and implement green infrastructure as part of their core business, they can continuously improve and update the content of their manuals in response to new construction technologies, materials, and changes in the urban environment. In Shibuya, where adapting to changes in land use and climate conditions is essential, this flexibility to update manuals is crucial.

On the other hand, it has been pointed out that "while private sector participation brings innovation, it may also raise issues regarding transparency and reliability [38]". Manuals created by private companies may contain promotional content or sales-oriented intentions aimed at steering users toward their own services, and may fail to fully earn the public's trust due to concerns about impartiality. Furthermore, when manuals are provided as corporate materials, they may be less visible to the public, potentially limiting their accessibility. Additionally, because content and policies vary by company, there is a lack of consistency among manuals, which can lead to inconsistencies and confusion in the information provided. Therefore, for private companies to create manuals, a system is required that facilitates collaboration with other entities to organize and integrate information.

3.2.4 Academic Societies

In Japan, there are few examples of academic organizations independently publishing manuals on how to create rain gardens. Even in academic papers on rain gardens, the standard approach is to analyze and evaluate existing case studies regarding construction and maintenance. One notable example is the "Guidebook on How to Create Rain Gardens" produced by the Center for Community Engagement at Fukuoka University [39]. This guide is distributed in the form of a pamphlet to participants at events hosted by the Center as part of its outreach efforts. While researchers studying green infrastructure such as rain gardens sometimes come together to organize their own seminars and workshops, they do not engage in systematic outreach activities as an academic organization. One example is an online seminar on creating rain gardens at home, featuring Professor Fukuoka from Tokyo University of Agriculture.

As for examples overseas, Michigan State University, the University of Michigan, and Oregon State University have created and published guidelines on how to build rain gardens at home or in nearby natural areas. Michigan State University and the University of Michigan are collaborating with institutions such as the University of Birmingham in the UK to produce a guidebook on rain garden installation created by Paige Hughart of the University of Michigan [40]. Because numerous other organizations are involved in this guidebook, it contains a wealth of information, covering everything from rain garden design concepts to plant selection methods and maintenance manuals. Therefore, both the reliability of the manual and the level of expertise regarding rain gardens are quite high. Regarding the ability to update the manual, since it was published in 2024 and the environmental conditions around Michigan have not changed significantly since then, updates are not necessary for home installations; however, should the need arise, it is anticipated that new research will be conducted by academic institutions.

Research and guideline development by academic organizations are generally made public, so accessibility to the general public is extremely high. Furthermore, since most of the people creating the manual are researchers in green infrastructure, they possess extensive knowledge of rain gardens. There are also many examples of actual rain garden installations at the laboratory level, ensuring a high degree of accuracy. On the other hand, accessing academic journals or university websites is not something people do casually unless they are interested, so it is unlikely that simply publishing the manual would have a significant effect on widespread public adoption. Academic institutions in the vicinity of Shibuya Ward include Aoyama Gakuin University and the University of Tokyo's Komaba Campus; however, when creating a manual, it is necessary to have a means of disseminating the knowledge held by these organizations to a wider audience.

3.2.5 Volunteers

There are very few examples of volunteer organizations publishing manuals, and even if they do exist, it is highly likely that they do not appear in search results.

In Japan, the Kumamoto Rain Garden Partnership has published a manual [41]. On the website operated by this organization, step-by-step instructions are provided for constructing a sunken-type rain garden—the most common form for residential installations—which collects, stores, and filtrates rainwater from the roof. Additionally, the page includes a section for uploading rain garden maintenance guidelines and planting guidelines, but it has not been updated.

Overseas, there are examples of volunteer groups that collect information on rain gardens collaborating with local governments and universities to create manuals. For instance, the manual on rain gardens around Lake Michigan, which was introduced in the section on academic societies, was developed in collaboration with the Rain Catchers Collective, a volunteer group within Friends of the ROUGE [40]. However, even overseas, there are no examples of volunteer groups alone publishing step-by-step manuals with a high degree of accuracy.

As described, there are very few examples of volunteer organizations creating manuals on rain gardens, and given their limited influence in promoting such gardens to the public, it is considered difficult for volunteer organizations to take the lead in creating manuals for the implementation of rain gardens in Shibuya.

3.2.6 When Implementing

We will evaluate the factors necessary for creating the manual, including the impact on citizens—such as the manual's accessibility and reliability—as well as knowledge of rain gardens and the ability to update the manual. Of the five entities listed above, the national government is considered to have sufficient influence over citizens, while local governments such as the Tokyo Metropolitan Government also exert strong influence over other local governments. Regarding knowledge, academic organizations hold a clear advantage. It is believed that all entities possess the ability to update the manual. Furthermore, looking at examples from overseas, there are many cases where academic organizations, with support from public institutions such as the national government, have created and published manuals. Based on the above, it is considered most effective for nearby universities to develop a manual for the implementation of rain gardens in Shibuya Ward with government assistance.

3.3 Operating Body for Construction

The operating body responsible for construction must possess technical capabilities—including experience, knowledge, and equipment—as well as sufficient funding, labor capabilities, and investment in rain gardens. We will identify the most suitable entity that meets these criteria.

3.3.1 Country

Examples of the national government undertaking construction projects are scarce. In particular, since green infrastructure is still in its early stages of adoption in Japan, national agencies such as the MLIT focused on creating an enabling environment that supports other entities in implementing green infrastructure; therefore, it is unlikely that the government will immediately begin installing green infrastructure on its own.

Even in international examples, while the U.S. government establishes national-scale policies, the actual implementation of specific projects is carried out by individual states. In Singapore, where green infrastructure for stormwater management is being introduced on a national scale, the government's role is limited to creating manuals and guidelines. The Public Utilities Board (PUB), Singapore's national water authority, has introduced a certification system for rain gardens constructed by other entities, whereby assessing compliance with standards and providing feedback, PUB has successfully incorporated the government's intentions regarding rain garden construction.

In Japan, the lack of experience—specifically, the fact that the national government has never actually constructed rain gardens itself—poses a hurdle if the government were to undertake such projects. However, the government likely possesses a wealth of knowledge gained through the creation of manuals, and it has already established information networks and cooperative frameworks through communication with experienced rain garden practitioners, particularly during the compilation of case studies. Rather than possessing technical expertise per se, it can be said that the government has the authority and capacity to implement large-scale national projects. However, the key issue remains whether it will direct these resources toward rain gardens, considering the government's current policy for introducing green infrastructure nationwide is to have prefectures, municipalities, and private organizations undertake the actual construction and install them in various locations.

3.3.2 Local Governments

3.3.2.1 Tokyo

The Tokyo Metropolitan Government has constructed several rain gardens, which are featured in the "Rainwater Green Infrastructure Concept Book [25]." The government took the lead in developing a total of eight sites: Oshima Komatsugawa Park, the Zenpukuji River Intake Facility, Takaido Park, Rokusen Park, Musashi Kokubunji Park, the former Ooguri River floodplain, the former Sakai River floodplain, and Meiji Park, all at various metropolitan facilities, including parks, riverbeds, and water supply facilities. Even though these were all developed by the Tokyo Metropolitan Government, they are diverse in design, including differences in the signage for rain gardens between the two sites we inspected. At Meiji Park, although the term "Rain Garden" appeared on the park map, there were no signs or educational material near the rain garden to indicate its purpose or provide information about it. At Takaido Park, there was a large, conspicuous sign right in front of the rain garden, clearly stating that the rain garden was installed by the Tokyo Metropolitan Bureau of Urban Development as part of the Rainwater Infiltration Project, also explaining the system behind the rain garden and the benefits it provides.

Regarding the design of the installations, Meiji Park features a system where rainwater falling on over 7,500 square meters of wooded areas within the park flows into a single large rain garden via a separately installed stream. Takaido Park has three small-scale rain gardens, each designed differently "to gather information on plant establishment and maintenance." In fact, the Tokyo government conducted a quantitative survey of rainwater retention and infiltration effects at Takaido Park. The results confirmed that these rain gardens possess filtration performance comparable to existing retention and filtration facilities and can be developed based on the same principles. Additionally, significant thermal mitigation effects were observed, with temperatures lower compared to surrounding land on extremely hot days; the difference being approximately 4°C cooler in comparison to lawn and approximately 14°C cooler compared to paved surfaces. The inclusion of this information in the "Rainwater Green Infrastructure Concept Book" has created a positive cycle making information on green infrastructure more accessible to the public.

Tokyo has much insight, experience, and technology in building rain gardens, through the 8 rain gardens it has built before. It has established a firm cooperation structure with experts on green infrastructure, so there is no doubt it can sufficiently install rain gardens as it decides. Furthermore, Tokyo Prefecture is one of the richest out of the 47 prefectures in Japan, as it is the capital of the country. In numbers, Tokyo has a budget size of 18.7 trillion yen, of which, Urban Development and Management Expenses take up 12.4 billion. The Urban Development and Management Department is responsible for the Concept Book as well as maintenance of all the rain gardens that Tokyo Prefecture owns.

However, it is up to the prefectural government to choose prefecture-owned land such as Yoyogi Park or Aoyama Park, both within Shibuya Ward, to build the next rain gardens, meaning there is no promise at all that it will be built any time soon.

3.3.2.2 Shibuya Ward

No rain gardens have been identified as publicly available in Shibuya Ward. Consequently, there are no known cases where the ward has taken the lead in constructing or maintaining such gardens. Among the other 23 wards, Suginami Ward has held workshops and residents' meetings to collaborate with residents in creating rain gardens such as Kashinomiya Park and Momoiharappa Park [25]. In Edogawa Ward and Shinagawa Ward, there are also examples of the ward installing rain gardens within parks; furthermore, in Musashino City, Fuchu City, and Hachioji City, rain gardens have been developed through workshops targeting citizens, designated park managers, and local landscaping companies.

As for examples overseas, New York City is leading the development of rain gardens and has installed more than 7,000 by 2024 [42]. In Portland, the Bureau of Environmental Services has four divisions responsible for the construction of green infrastructure, including rain gardens: the Watershed Management Section and the Sustainable Stormwater Management Section within the Watershed Services Division; the Stormwater Systems Rehabilitation Section within the Engineering Division; and the Public Relations Section within the General Affairs Division [14]. When the Bureau of Environmental Services is the lead agency, it drafts the development plan and consults with the Bureau of Transportation, and when the Bureau of Transportation is the lead agency, it carries out the installation under the guidance of the Bureau of Environmental Services. Thus, a distinctive feature of Portland is the formation of flexible, cross-functional teams.

In Shibuya Ward, since there are currently no rain gardens installed by the ward, there is no accumulated experience, and knowledge is not yet sufficient. While it may be possible to utilize equipment used in other projects for rain gardens, that alone is not necessarily sufficient. Therefore, in terms of technical capability, at least in the initial stages of introducing rain gardens, cooperation with other entities that possess experience, knowledge, and equipment is essential.

Financially, Shibuya Ward's 2026 general account budget exceeds 152.5 billion yen, including 7.3 billion yen for environmental expenses and 17.7 billion yen for civil engineering expenses [43]. Rain garden development is a relatively small-scale initiative, and the financial burden is lighter compared to large-scale public works projects. Consequently, securing funds for rain garden construction is relatively straightforward. Regarding personnel, Shibuya Ward has departments such as the Parks Division, the Roads Division, and the Environmental Policy Division which we were able to confirm that they would be the departments who would work together if Shibuya Ward were to make raingardens through our interview with staff at the Ward. While it is not impossible to secure staff from these departments, given the need to balance their responsibilities with other duties, it would likely be difficult to secure staff dedicated exclusively to rain garden operations.

3.3.3 Private Enterprises

In Japan, it is common to see private companies—such as landscaping firms and civil engineering firms—undertaking construction work as part of exterior landscaping and redevelopment projects. Commercial facilities and office buildings often incorporate planting strips and permeable paving designed to temporarily store and filtrate stormwater, and since these require a combination of expertise in soil improvement, drainage design, and planting plans, they are typically constructed by companies with specialized technical capabilities. The Tokyo Metropolitan Government also states that "the development of stormwater infiltration facilities requires specialized knowledge at each stage of design, construction, and maintenance" (Tokyo Metropolitan Government Bureau of the Environment). Another characteristic of these companies is that they possess networks for procuring heavy machinery and materials, enabling them to maintain a system that ensures a stable supply of the equipment and labor required for construction. Regarding funding, since construction is carried out as a project based on the client's budget, these companies can handle projects of a certain scale.

In Berlin, Germany, stormwater management is incorporated as a key design element in redevelopment projects. For example, in the redevelopment of Potsdamer Platz, a system for storing and reusing stormwater on-site was introduced as a measure against urban flooding, with private companies specializing in architecture, landscaping, and civil engineering responsible for construction. This project employs a system that collects rainwater falling on building rooftops and plazas into underground tanks, then utilizes and discharges it in stages; it is regarded as an attempt to reconstruct the water cycle within the urban environment. Furthermore, the city as a whole maintains that "rainwater should be allowed to filtrate or evaporate on-site as much as possible [44, 45]", and on-site treatment has become the basic policy for new construction and redevelopment projects. German environmental policy places a strong emphasis on "decentralized stormwater management," and the concept of treating stormwater in a decentralized manner across the entire city is widely adopted (Goethe Institute).

For these projects, in addition to precise construction based on design drawings, on-site adjustments that take into account soil conditions and water flow are necessary, making specialized knowledge and technical expertise indispensable. In this regard, it is noted that "green infrastructure requires design and construction tailored to site conditions", and private companies with practical experience play a significant role [46].

On the other hand, since construction is carried out as a business venture, securing sufficient funding is a prerequisite [38].

3.3.4 Academic Societies

Examples of rain gardens installed on university campuses are common both in Japan and abroad. In Japan, Kumamoto Prefectural University serves as one such example [47]. The university has installed a rain garden with a catchment area of 178 square meters on its sports field and is verifying the rain garden's ability to reduce runoff by monitoring inflow, outflow, and soil infiltration capacity during precipitation events, including heavy rains. Regarding the maintenance of the rain garden, the professor himself checks its condition and tends to the plants approximately once every three months. This initiative is led by Professor Yukihiro Shimatani, who is a member of the "Kumamoto Rain Garden

Partnership," a collaborative organization involving the national government, local municipalities, universities, and businesses. Consequently, the rain garden at Kumamoto Prefectural University can also be viewed as an example of collaboration among multiple entities.

The Zenpukuji River flows through the grounds of Iogi Elementary School in Suginami Ward, making it a school with a close relationship to water [48]. Here, Professor Shimotani, mentioned earlier, visits to give lectures, and a program is conducted where students actually build rain gardens using shovels. Since this program receives cooperation from Suginami Ward, it also demonstrates collaboration between an academic institution and a local government. Furthermore, because a rain garden exists on the school grounds, the school serves as a venue for green infrastructure promotion events hosted by the ward. Similarly, at Mai-no-Sato Elementary School in Koga City, elementary school students, contractors, and volunteers are currently working together to create a rain garden under the supervision of Professor Hayashi from Kyushu University [49].

Otsuma Women's University renovated existing facilities at its Chiyoda and Tama campuses to install rain gardens [25]. Although detailed information has not been made public, a sign explaining the garden's benefits has been erected at the Chiyoda Campus rain garden. However, while both rain gardens possess rainwater infiltration capabilities, they lack vegetation, so they are unlikely to attract much attention or contribute significantly to environmental education.

The University of Michigan-Dearborn has installed a rain garden next to its Environmental Interpretive Center (EIC) on campus [12]. This rain garden was established in 2008 and has gradually expanded in size since then. Although not explicitly stated, since the EIC is part of the University of Michigan's outdoor educational programs, it is likely that participants and students are responsible for its maintenance. Additionally, native plant species from southeastern Michigan have been planted around the depression that functions as the rain garden. According to the University of Michigan, this includes hundreds of species of grasses, herbs, and shrubs, as well as dozens of other plant species. In addition to the plants, the environment has created habitats for native Michigan wildlife. Specifically, because of its recognized ability to protect monarch butterflies, it has been designated as a certified Monarch Waystation.

As such, examples of rain gardens being installed on university campuses and within elementary schools are common. When installing rain gardens at academic institutions, there is sufficient knowledge and manpower regarding rain gardens, and if external instructors are invited, their expertise can also be leveraged. On the other hand, regarding the equipment and funding required for installation, if cooperation from other entities cannot be secured, resources may be insufficient, and even if a rain garden is installed, it is expected to be on a small scale. However, since the only university campuses in Shibuya Ward with space available for rain gardens are Aoyama Gakuin University's Shibuya Campus, Kokugakuin University's Shibuya Campus, and Sacred Heart University, installation would be limited to these three locations. On the other hand, there are many elementary schools in the area. Following the example of Iogi Elementary School, which installed a rain garden as part of its educational program on the Zenpukuji River, rain gardens could be incorporated as part of educational activities focused on the Shibuya River. However, since land is scarce in Shibuya Ward, constructing a new rain garden within an elementary school would require reducing the size of other areas, such as the schoolyard. Furthermore, because construction sites are limited within university campuses, the number and scale of rain gardens may be reduced.

3.3.5 Volunteers

While there are examples of local governments and academic organizations installing rain gardens using the expertise and manpower of volunteer groups, there are almost no instances of volunteers independently installing rain gardens in public spaces. This is likely because the roads and locations where rain gardens would be most effective are already owned by other entities, and volunteer groups lack the necessary funding to acquire them. As a result, what can be called volunteer-led rain garden installation is limited to small-scale rain gardens at private residences designed to allow rainwater from rooftops to filtrate the soil.

Within Shibuya Ward, small rain gardens installed at private homes are insufficient for preventing flooding during heavy rains. Therefore, it appears that introducing rain gardens to Shibuya led primarily by volunteer groups alone is not feasible at this stage.

3.3.6 When Implementing

Construction requires technical expertise—including experience, knowledge, and equipment—as well as funding and manpower. As mentioned earlier, it is difficult for entities at the smallest scale, such as large national governments or volunteer groups, to undertake such projects. The Tokyo Metropolitan Government holds an overwhelming advantage in terms of financial resources and also possesses the necessary experience, having already created several rain gardens in parks within the city. While academic institutions and universities possess the necessary knowledge, their numbers are limited; the only viable option within Shibuya Ward is to convert a portion of an elementary school's grounds into a rain garden. Private companies have ample technical expertise and labor resources for construction, and they also possess the financial resources compared to volunteers and academic institutions. Regarding the issues of reliability and public interest, it is necessary to devise ways to construct rain gardens that earn the trust of citizens. To achieve this, it is anticipated that private companies will need to collaborate with public agencies and receive support or be commissioned by them.

3.4 Operating Body for Maintenance

The operating body responsible for maintenance must possess the following: staying power, manpower, funding, time, motivation, and technical skills. Funding need only be sufficient to cover the purchase of tools and similar expenses. While technical skills are required for tasks such as pruning and leaf removal, these can be supplemented with manuals. We will identify the optimal entity that meets these conditions.

3.4.1 Country

There are almost no examples of the national government being directly involved in the maintenance of rain gardens, and even if such examples exist, it is highly likely that they do not appear in search results. While the national government simply has more than enough manpower and funding to maintain rain gardens, it is difficult for it to focus exclusively on them. While the national government's objective is to promote the nationwide adoption of green infrastructure as a whole, the specific initiative to introduce rain gardens in Shibuya falls outside its direct jurisdiction. In other words, we cannot expect the national government to devote the time, sustained effort, or enthusiasm required for Shibuya's rain gardens.

3.4.2 Local Governments

3.4.2.1 Tokyo

Although the Tokyo Metropolitan Government is listed as the managing entity in the Rainwater Green Infrastructure Concept Book, no clear information was found indicating that the metropolitan government actually takes the lead in maintaining rain gardens. Furthermore, even when examining examples from overseas, no publicly available information was found indicating that states or regional administrative bodies—equivalent to the Tokyo Metropolitan Government—directly maintain rain gardens. In the case of the Tokyo Metropolitan Government as well, the conditions required of a maintenance entity are similar to those at the national level, and it is considered unlikely that the government would be well-suited to the ongoing management of individual rain gardens within Shibuya Ward.

3.4.2.2 Shibuya Ward

As mentioned in Section 3.3.2.2, there are no rain gardens in Shibuya Ward that are clearly open to the public, so there are no examples of the ward taking the lead in their maintenance. In other wards and cities within Tokyo, the *Rainwater Green Infrastructure Concept Book* lists the local government—as the landowner—as the manager; however, perhaps because many rain gardens have been completed recently, there was no information on websites or elsewhere explicitly stating that the wards or cities are taking the lead in maintenance.

Looking at examples overseas, in New York City, once the "warranty" period for green infrastructure (the first approximately three years during which the contractor is responsible for maintenance) ends, responsibility for maintenance is transferred to staff at the Department of Environmental Protection (DEP) [50]. As of 2022, approximately 100 staff members were responsible for about 4,000 green infrastructure sites, including rain gardens. Staff regularly remove trash, sediment, and weeds, and replant trees when necessary. In the future, even more green infrastructure—such as rain gardens—is expected to be built in addition to the existing 11,000 sites, and responsibility for managing many of these is scheduled to transfer to the DEP in the near future. It will be difficult for the DEP to continuously secure enough staff to manage all green infrastructure. Therefore, volunteers will be needed to assist with at least basic ongoing maintenance. The role of citizen volunteers in New York City's maintenance efforts is discussed in detail in Section 3.4.5. In Portland, three departments manage green infrastructure such as rain gardens: the Sustainable Stormwater Management Section of the Watershed Services Division, the Design Section of the Engineering Division, and the Collection System Operations and Maintenance Section of the Sewer Division [14].

District employees are generally considered to possess the technical skills and experience required for day-to-day maintenance tasks compared to citizen volunteers. Furthermore, as mentioned in Section 3.3.2.2, Shibuya Ward has the financial capacity to allocate sufficient funds for maintenance. Additionally, regarding sustainability, once a dedicated rain garden management unit is established, the unit will remain in place even if personnel changes occur, regardless of individual motivation, making it easier to maintain a formal management structure. However, there is a possibility that other high-priority tasks will take precedence, causing maintenance to become insufficient. From this perspective, it can be said that in a ward handling a wide range of tasks, the time allocated to rain garden maintenance is limited. Regarding manpower, since the number of rain gardens is small during the initial implementation phase, ward staff alone may suffice; however, as seen in overseas examples, as rain garden development progresses and their numbers increase, it becomes difficult to secure sufficient personnel for the maintenance of all rain gardens. Therefore, from a long-term perspective, cooperation with citizen volunteers and others will likely become necessary.

3.4.3 Private Enterprises

In Japan, one example is the management of green spaces in urban office buildings and commercial facilities. At these facilities, private companies—such as building management firms and landscaping contractors—are continuously responsible for the maintenance of planting beds and rooftop green spaces. Routine cleaning, pruning, and seasonal maintenance tasks are planned as part of standard operations, and systems are in place to ensure that a consistent level of maintenance is maintained even if personnel change. The fact that a system has been established that does not depend on individual motivation or availability is a key feature from the perspective of ensuring continuity and securing manpower.

In Singapore's ABC Waters Program as well, there are many examples where private management companies are responsible for the maintenance of stormwater management green spaces installed in commercial facilities and public spaces. In hot and humid environments, plants grow rapidly, and the disposal of fallen leaves and accumulated debris is required frequently; therefore, it is essential to have an entity that can secure a stable workforce and sufficient time. This program states that "stormwater management facilities must maintain their functionality and aesthetic value through proper maintenance [51]."

These examples demonstrate that private companies have the capacity to incorporate the necessary maintenance tasks into their operations and maintain a system for their continuous implementation. In particular, since "regular inspections and management are essential for the maintenance of green infrastructure", the ability to deploy multiple staff members and manage schedules is a key distinction compared to systems reliant on individuals or volunteers [52].

On the other hand, regarding the cost burden of outsourcing management and the fact that operations are contract-based, it has been pointed out that "while private-sector involvement enhances efficiency, it may also entail challenges related to cost burdens and fairness [38]."

While such maintenance systems are effective for large-scale facilities, it is difficult to establish similar mechanisms at the level of individual residences, making the development of simple and sustainable management methods a key challenge.

3.4.4 Academic Societies

In Japan, when academic organizations manage rain gardens, elementary schools often take on this role. As mentioned in the section on academic organizations above, at Iogi Elementary School, students installed the rain garden and maintain it themselves [48]. Additionally, there is a rain garden at Kamoto Ajisai Park in Edogawa Ward. While the ward itself is the official administrator, the rain garden is maintained by students from the adjacent Koiwa Fifth Junior High School [25].

Rain gardens installed on university campuses are often managed by students or administrative staff. However, many universities with rain gardens—including the aforementioned University of Michigan—do not specify who is responsible for their maintenance.

One example where this is clearly stated is the rain garden at Chiba University's Matsudo Academic Link [53]. This site won the CLA Award 2024 and was recognized in part because the rain garden is maintained by a student group called the "Rain Garden Club."

There are also examples of collaboration with local wards and cities. In New York City, many rain gardens are managed by the Parks Department, but volunteers and students, as well as Parks Department staff, participate in their maintenance.

As such, when members of academic organizations are responsible for maintenance, there is sufficient manpower and time available. Furthermore, duty rosters and committees in elementary schools ensure continuity, and because they are part of the school's internal structure, they carry a degree of enforceability. Volunteer groups like the "Rain Garden Club" are also highly motivated, so sustained maintenance can be expected. On the other hand, because a large number of people are involved, manuals and other resources are necessary to ensure accurate maintenance techniques. Regarding funding, since it is difficult for the organizations alone to secure the necessary funds, cooperation with other entities that have financial resources is desirable. If implemented in Shibuya, as mentioned in the construction section, the district has many elementary schools, so these resources can be fully utilized. In such cases, it would be necessary to install rain gardens in the vicinity of the schools. In such cases, schools are required to install rain gardens either on their premises or in the surrounding area.

3.4.5 Volunteers

Kyoto's rain gardens are primarily managed by volunteers. The City of Kyoto has established a "Green Volunteer Center" to facilitate the formation of volunteer groups, and these groups receive support from the city. According to the City of Kyoto, while there are no specific manuals for the maintenance of rain gardens, the registration screening process for volunteer groups is rigorous; only groups deemed to possess sufficient knowledge and skills are permitted to participate in maintenance.

A similar initiative is underway in Portland. Unlike Kyoto, however, one can become a "Green Street Steward" with just a few minutes of registration [54]. In this case, the City of Portland has published a very detailed maintenance manual, enabling even volunteers with limited knowledge to perform maintenance work. The manual primarily covers litter pickup and plant care; as with New York City, discussed later, it is believed that the city or companies contracted by the city handle the maintenance of the rain garden's structural components.

In New York City as well, some rain garden maintenance is carried out by volunteers. However, according to amNY, maintenance of rain gardens in the city has been neglected, and trash has accumulated [55]. The causes cited include a lack of regular patrols by the DEP and a shortage of actual volunteer activity. As such, when motivation or time is insufficient, entrusting maintenance entirely to volunteers risks creating poorly maintained rain gardens.

Based on the above examples, volunteer-led maintenance is feasible if there is sufficient manpower, and if there are strict screening processes like those in Kyoto or beginner-friendly manuals like those in Portland, technical skills and knowledge are also sufficient. For the continuous management of rain gardens, it is important that the volunteers themselves approach the task with enthusiasm.

In the case of implementation in Shibuya, according to the Shibuya Ward Basic Green Plan, while Shibuya residents generally lack volunteer experience, those who have participated once demonstrate a willingness to continue taking action [18]. By actually holding events and securing a sufficient number of participants, it is expected that continuous management will be possible. Regarding funding, since volunteer-led maintenance does not incur significant costs, it is believed that volunteers can provide some tools, such as tongs, themselves.

3.4.6 Performance Assessments of Rain Gardens in Tokyo

We conducted evaluations of rain gardens already installed within Tokyo Prefecture, focusing on how they were actually being maintained. We visited 12 sites, a total of 22 rain gardens, on 2026.4.25 (Sat), 2026.4.26 (Sun), and 2026.4.29 (Wed). There was rainfall in Tokyo 48 hours or more before each of the assessments were made: 22mm on 2026.4.22, and 46mm on 2026.4.27. For each, we applied the visual inspection criteria as developed in "Performance Assessment of Rain Gardens [17]." The 12 sites were selected on a similar criterion as this previous study, being (1) on public sites that were free to access, (2) availability of site information (e.g., site plans, responsible bodies, implementation year etc.), and (3) proximity to our living areas.

Although this study dived into evaluating whether hydric soils or emergent vegetation were present, the first requires digging deep in the ground, and the latter calls for accurate knowledge of plants. Thus, our evaluations were limited to visual observations of (1) presence of ponded water and (2) failing vegetation, two of the four criteria that they utilized to determine whether it was functional or nonfunctional. As the paper explains that “it is believed that these rain gardens failed due to a lack of maintenance,” for our research it is key to gain recent information about the maintenance of rain gardens. Thus, we did not technically reach conclusions of functional/nonfunctional but landed on adequate maintenance/insufficient maintenance observed through the perceived functionality, evaluated through multiple angles.

The rain gardens were examined thoroughly, especially focusing on infiltration issues and vegetation health. There were in fact impediments drainage at multiple rain gardens that either fell into (1) sediment accumulation, (2) clogging of inlet/outlet structures, (3) erosion of the rain garden. (4) presence of vegetation, and (5) health of plants (H:Healthy, U:Unhealthy, such as Weed overgrowth, and wilting, D:Designed Absence of Vegetation) was also examined, considered by color, growth, and quality of the leaves, stem, and flowers in mind, and whether it was designed to have plants in the first place which was made sure of by referencing plans and photos taken soon after installation.

Each rain garden had its own characteristics, and it was further confirmed that the concept of “rain garden” is outlined substantially larger in the minds of Japanese regional governments, as some rain gardens consisted mainly of rocks and no vegetation, or were an improvement in the ground by adding infiltration material. It should also be noted that rain gardens on roads or sidewalks are a rarity in Tokyo, and an overwhelming majority were in parks.

The previous research focused on the presence of pond water more than 48 hours after rain. Upon careful inspection, none of the 23 rain gardens had any ponded water; thus, it has been omitted from the table below. 4 rain gardens had sediment accumulation, 6 had clogging of structures, 5 had erosion of soil, 6 rain gardens had plants, but they were not healthy, and another 6 did not have plants to start with. 9 out of 23 rain gardens had no issues with any criteria. Takaido Park 3, Momoi Harappa Park B, Tsurumaki 4chome Matsunoki Suzuki Citizen Green Space 3, Shimokita Raingarden Square, and Tokyo University of Agriculture rain gardens were the only 5 that had plants designed and had no issues at all. They all have differing bodies that maintain them, but the first three have the fact that they are one of multiple at the same park in common, while Shimokita Rain Garden Square was a site that was centered on a single rain garden as its main feature, and Tokyo University of Agriculture is an academic body with professors and students proficient in this area seeing to it. Either having more rain gardens to take care of,

Table 1: General Descriptions of the Assessed Rain Gardens

ID	Rain Garden Name	Year built	Source of Runoff	Responsible Body	Sign
1	Ooshima Komatsugawa Park 1	2024	Surrounding ground	Tokyo Prefecture Bureau of Urban Development	Yes
2	Ooshima Komatsugawa Park 2	〃	Surrounding ground	〃	Yes
3	Ooshima Komatsugawa Park 3	〃	Direct rainfall only	〃	Yes
4	Hamakawakita Park	2025	Direct rainfall only	Shinagawa Ward	No
5	Ooimachi Station West Exit Station Square	2026	Surrounding sidewalks	〃	Yes
6	Meiji Park	2024	Surrounding park pathways	Tokyo Prefecture Bureau of Construction	No
7	Takaido Park 1	2024	Surrounding grass	Tokyo Prefecture Bureau of Urban Development	Yes
8	Takaido Park 2	〃	Surrounding grass, park pathway	〃	Yes
9	Takaido Park 3	〃	〃	〃	Yes
10	Kashinomiya Park A	2024	Surrounding compacted ground	Suginami Ward	Yes
11	Kashinomiya Park B	〃	〃	〃	Yes
12	Kashinomiya Park C	〃	〃	〃	Yes
13	Kashinomiya Park D	〃	〃	〃	Yes
14	Kashinomiya Park E	〃	？	〃	N/A
15	Momoi Harappa Park A	2026	Surrounding ground	Suginami Ward	Yes
16	Momoi Harappa Park B	〃	Surrounding grass, park pathways	〃	Yes
17	Tsurumaki Yon-Chome Matsunoki Suzuki Citizen Green Space 1	2024	Park pathways	General Incorporated Foundation Setagaya Trust Machizukuri	Yes
18	Tsurumaki Yon-Chome Matsunoki Suzuki Citizen Green Space 2	〃	Overflow from temporary storage in warehouse downspout to rainwater tank	〃	Yes
19	Tsurumaki 4chome Matsunoki Suzuki Citizen Green Space 3	〃	Direct rainfall only	〃	Yes
20	Setagaya Trust Machizukuri Visitor Center	2023	Overflow from temporary storage of roof downspout in rainwater tank	Incorporated Foundation Setagaya Trust Machizukuri	Yes
21	Shimokita Raingarden Square	2022	Surrounding ground	Setagaya Ward	Yes
22	Kinuta Children's Park	2023	Direct rainfall only	Setagaya Ward	Yes
23	Tokyo University of Agriculture	2024	University pathways	Tokyo University of Agriculture	No

Table 2: Performance Assessments

ID	(1)	(2)	(3)	(4)	(5)	Designed Surface Type
1	No	No	Yes	Yes	U	Vegetation and Rocks
2	No	No	No	Yes	U	〃
3	No	No	Yes	Yes	U	〃
4	Yes	Yes	No	Yes	U	Vegetation
5	No	No	No	No	D	Rocks
6	No	Yes	Yes	No	D	Rocks
7	Yes	Yes	No	Yes	H	Vegetation
8	No	No	No	No	D	Rocks
9	No	No	No	Yes	H	Vegetation
10	No	No	No	No	D	Infiltration Material
11	Yes	Yes	No	No	D	Infiltration Material
12	Yes	Yes	No	Yes	H	Infiltration Material
13	No	No	Yes	Yes	H	Soil
~~14~~						
15	No	No	Yes	Yes	H	Vegetation and Rocks
16	No	No	No	Yes	H	Vegetation and Rocks
17	No	Yes	No	Yes	H	Infiltration Material
18	No	No	No	Yes	U	Infiltration Material
19	No	No	No	Yes	H	Infiltration Material
20	No	No	No	Yes	U	Infiltration Material and Vegetation
21	No	No	No	Yes	H	Soil and rocks
22	No	No	No	No	D	Soil
23	No	No	No	Yes	H	Rocks

in other words, making the weight of rain garden maintenance substantial so it is not easily looked over, focusing specifically on it, or knowing more may lead to better functionality and maintenance. On the other hand, we could not find clear evidence that maintenance was being conducted regularly, and the analysis of our observations bring us to the consideration that there is no established “correct answer” for maintenance in Tokyo yet, and what ultimately matters the most is whether or not maintenance is actually being conducted or not. Division of roles and planning of maintenance will be crucial for rain garden longevity in Shibuya Ward.

By studying many already installed rain gardens, we were able to additionally notice some things that should be addressed when rain garden installation happens in Shibuya. First, there is a drastic disparity of the understanding and image of rain gardens, not just within Tokyo and even more compared to examples abroad. Second, signs as shown in Table 1 are now a major addition to rain gardens, and they would be indispensable for Shibuya as well, especially with small rain gardens like rain garden 14 which could not be found despite much time spent searching with no avail. Third, the observations we could make would roughly be the same as a volunteer would be able to do often as inspection without too much burden or specific machinery. Meaning that if we can find issues that must be improved to provide functionality, volunteers would be able to find it without too much trouble and in turn directly contribute to the maintenance.

Figure 4: Takaido Prak3 (ID9)

Figure 5: Meiji Park (ID 6)

Figure 6: Ooimachi Station West Exit Station Square (ID 5)

3.4.7 When Implementing

Based on the above, it is difficult for the national government or the Tokyo Metropolitan Government to serve as the primary entities responsible for maintenance and management. As for private companies, if rain gardens are installed throughout Shibuya Ward, it is considered quite effective if a process for regular patrols can be established. However, since maintenance can only be performed on rain gardens constructed by the same company, it is difficult to cover the entire ward. If patrol duties are incorporated into work hours, there is no issue with time allocation. Since it is part of their job description, a sense of obligation arises, reducing the likelihood of neglecting maintenance. For similar reasons, maintenance by elementary school students is expected to be sustainable; however, this approach has the drawback of limiting the locations where rain gardens can be created. Additionally, since elementary school students lack the necessary technical skills and knowledge, they require external instructors. Volunteers can be an ideal group if they can form an effective management organization like Stewardship, as they offer continuity and motivation.

However, when individuals volunteer on their own, they cannot judge whether their knowledge and skills are adequate, which reduces reliability. Much of the volunteer-led maintenance carried out to date has been based on certification by public agencies and the dissemination of knowledge. Given that a shortage of personnel is a concern for maintenance centered on Shibuya Ward, it would be optimal for the ward to participate in maintenance by supporting volunteers.

3.5 Approaches to Cooperation

Collaboration among the various entities involved in manual development, construction, and maintenance is also crucial. Given that collaboration tends to proceed more smoothly between entities that already have a history of working together—such as government agencies and universities, or government agencies and contractors—we will examine appropriate approaches to collaboration between the entities identified as suitable in Sections 3.2, 3.3, and 3.4.

Regarding the coordination framework at each stage, looking at previous examples, in New York, for instance, construction companies install rain gardens, and approximately three years later, responsibility for maintenance is transferred to staff from the Department of Environmental Protection [51]. Additionally, for some rain gardens, the Parks Department partners with local students to carry out maintenance. Furthermore, in Tokyo, there are several rain gardens where local residents and the government collaborated on the installation [25].

As discussed in Section 3.2, when implementing rain gardens in Shibuya Ward, it would be effective for academic organizations with expertise in rain gardens—such as nearby universities—to create manuals with the cooperation of the government. Furthermore, as indicated in Section 3.3, it is appropriate for private companies to undertake construction with the support or through contracts with public agencies. Additionally, as noted in Section 3.4, regarding maintenance, it is desirable for the ward to support maintenance carried out by resident volunteers.

Coordination between each stage is also crucial. It is considered appropriate for the government to provide support to both the entities responsible for manual development and those responsible for construction. As for the government, there is no precedent of the national government having been responsible for both drafting and implementing manuals, and we were unable to find any such precedent at the ward level either. In contrast, the Tokyo Metropolitan Government has accumulated experience in both areas, such as the creation of the Rainwater Green Infrastructure Concept Book and the development of rain gardens by the Bureau of Urban Development. Moreover, regarding maintenance, it is desirable for the ward to support citizen volunteers. Shibuya Ward belongs to the unique 23-ward system, which places it directly under the Tokyo Metropolitan Government without going through the City of Tokyo; this administrative structure facilitates cooperation between the prefecture and the ward more easily than in other regions. Therefore, it is considered optimal for the Tokyo Metropolitan Government to oversee both manual development and construction, with academic organizations and private companies handling the practical work. Furthermore, for the maintenance and management phase, a collaborative framework in which Shibuya Ward certifies and supports resident volunteers while coordinating with the Tokyo Metropolitan Government is considered the most effective approach.

4 Conclusion

Based on the above, a multi-stakeholder collaboration model—which leverages the strengths of each entity in a complementary manner—is more suitable for the introduction of rain gardens in Shibuya Ward than a model operated by a single entity.

Our specific conclusions regarding the entities involved in implementing rain gardens in Shibuya Ward are as follows.

We believe it would be most effective for academic organizations to take the lead in creating the manual, with support from public institutions such as the national government and the Tokyo Metropolitan Government, and to publish it under both names. Academic organizations can provide the necessary expertise on rain gardens, while public agencies possess the influence to reach citizens and the capacity to regularly update documents. Furthermore, publishing the documents under multiple names increases their visibility in search results, ensuring they reach a wider audience. By making manuals and guidelines widely accessible, we not only provide the information necessary for implementing rain gardens but also help popularize the concept of rain gardens, thereby contributing to environmental education and awareness.

It is desirable for private companies to take the lead in construction, with the Tokyo Metropolitan Government acting as the contracting authority. Only private companies possess the technical expertise and labor force required for road construction and planting. Furthermore, the Tokyo Metropolitan Government has experience as an entity that has already installed numerous rain gardens and possesses sufficient funding. Additionally, if the manual is created by the Tokyo Metropolitan Government and academic organizations, the Tokyo Metropolitan Government could contribute to the construction by utilizing the knowledge gained or organized during the manual's creation.

Regarding maintenance and management, a joint operation between Shibuya Ward and volunteers is considered optimal. Because Shibuya Ward and the residents volunteering are in close proximity, the transfer of technical skills and information is feasible. Furthermore, since the Tokyo Metropolitan Government and Shibuya Ward are closely involved in manual development and construction, collaboration—including information exchange—is straightforward. The more specialized knowledge required to assess and certify volunteers' skills and expertise can also be obtained from the Tokyo Metropolitan Government. Although there is no guarantee of the volunteers' long-term commitment, a survey of district residents indicates that once they participate in a greening campaign, 80% of them are expected to continue their involvement. Evidence supporting the capability of academic societies in maintenance was found from our observations; however, there is no applicable body within our Shibuya area, so their knowledge should be passed on through their creation of manuals.

The above constitutes an analysis of the relevant entities involved in introducing rain gardens in Shibuya. Although this paper focuses on the single municipality of Shibuya Ward, we believe this analysis of entities can be applied to other major cities with environments similar to Shibuya's. Furthermore, the two entities unique to Japan—prefectures and municipalities—could be applied not only within Japan but also to similar administrative structures, such as states and cities in the United States. Since there are still few examples worldwide of collaboration that transcends the boundaries between these entities, this could lead to the development of a maintenance system for green infrastructure.

There are still many challenges involved in implementing green infrastructure, such as rain gardens, and establishing a regular maintenance system to ensure their sustainable operation. Since this study is based on the assumption of implementation in Shibuya Ward, the next step will require either the actual installation of rain gardens in Shibuya Ward or a pilot implementation in cities where rain gardens already exist in order to investigate their actual effects and performance.

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Rainwater infiltration in city centres of Dutch cities

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Abstract

A reoccurring problem in Dutch cities caused by climate change is water nuisance; this is also the case in the historical city center of ´s-Hertogenbosch. The city is located at the end of two rivers, De Dommel and De Aa, where they join to become the Dieze that discharges into the Maas. When heavy rainfall occurs, almost all of it gets redirected into these rivers via drainpipes which causes high water levels that create problems for the Maas. Measures must be taken to move part of the water volume from the rivers to the soil through infiltration. Our hypothesis is that by taking these measures, we will help prevent problems such as foods while helping maintain a high groundwater level. We will try to achieve this by turning stone squares, playgrounds, and other non-permeable structures into more ecofriendly alternatives to allow for greater infiltration in the city center. By doing this we expect to achieve high groundwater levels while putting less load on the Dommel, Aa, Dieze and eventually the Maas.

Keywords

- Infiltration
- Urban spaces
- Script
- Water discharge

Introduction

The Netherlands is a country sensitive to water. his has several causes: two big rivers The Rijn and The Maas flow through, and terminate in The Netherlands [1], and that 26% of the land lays below sea level [2]. The country has therefore numerous defence systems against water such as the Afsluitdijk, a large dike separating the sea from a large manmade lake [3], The Deltawerken ,consisting of five storm surge barriers, two locks and six dams in response to the 1953 disaster [4] and 21 local water authorities have been founded to manage water systems [5]. ´s-Hertogenbosch has also had problems with water. In 1995 there was a well-known flooding in which the A2, a highway laying besides the city, got flooded [6]. ´s-Hertogenbosch is a city sensitive to water nuisance.

Although s-Hertogenbosch lays above the sea level, there are two rivers, The Dommel and The Aa, which come together into The Dieze. The Dieze then flows through ´s-Hertogenbosch h and ends into The Maas. When high rainfall occurs, the rivers carry a lot of water into the city, and when the water level of The Maas is too high, the water cannot flow further, increasing the risk of flooding. This makes the city vulnerable to floods. The two local water authorities, Waterschap De Aa en De Maas and Waterschap De Dommel, have therefore taken cautions to decrease the danger of floods. Firstly, they spent a lot of attention to enhancing water retention in the upper stages of the river. Mainly by making buffer zones and letting the river meander, increasing water infiltration and decreasing peak water discharges. Several measures have also been taken within the city. For example, quays have been improved and constructed, the drainage of waterways has been improved and, in some cases, rerouted and buffer zones have been created. All of this, along with further improvements, can be seen in Figure 1, and its translated caption in figure 2. This is all noted in a document called ´the building blocks book tackling high water´ on the site of Waterschap Aa en De Maas [7].

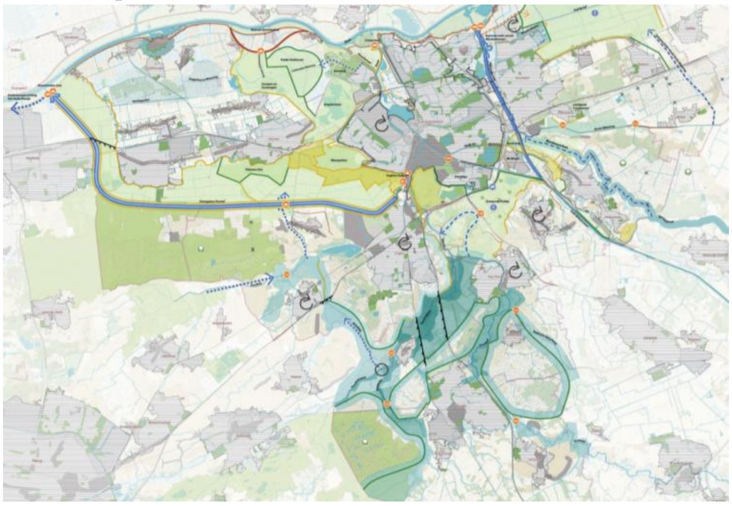

Figure 1, overview map of building blocks

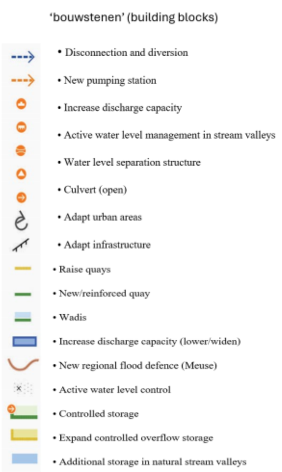

Figure 2 translated caption for figure 1.

Also shown in this image, are symbols that look like an arrow spinning in a circle in all built-up areas. This symbol means ‘adapting urban spaces’ which means adapting an urban area to climate change [8]. This is where this research becomes relevant, aiding urban spaces to adapting to heavy rainfall by letting water infiltrate better into the ground. This also decreases water discharge into the rivers. For this study, we are using the city centre of ´s-Hertogenbosch as a model area.

Purpose of the investigation

With high amounts of rainfall, de rivers around ‘S-Hertogenbosch carry a large volume of water. In The Netherlands a mixed sewer system is the most common system [9]. They are inexpensive and easy to construct. However, in this system, all water, rainwater, household water and rainwater, is connected to the same sewer. When high rainfall occurs, the sewers overflow fast and the water is diluted and drained. This means that, when the water from the sewer is disposed into surface waters, it pollutes the water. letting water infiltrate more into the ground, will release water tension on the sewers which then releases water tension on surfaces waters and keeps the surface waters clean.

The ground of ´s-Hertogenbosch contains a lot of sand, which lets water infiltrate very well [10]. However, it also means that the water sinks into the bottom very fast. This means that the groundwater level drops fast which then makes the upper layer of the ground dry and makes it harder for plants to reach water. Letting water infiltrate more into the ground will help supplementing the ground water [11] levels, keeping it high.

Research question

- What are the most effective methods to make water infiltrate better into the ground on urban areas and how can these methods be applied on the city center of 's-Hertogenbosch?

Method of investigation

the investigation is about the improvement of water infiltration in the ground on locations which allow this poorly. This research includes a method to demonstrate the effectiveness of water infiltration. This by building a script to simulate the water level of The Dieze. This is inspired by the ‘digital twin’ of the sewer in Rotterdam [12,13]. A digital twin is a 3D model that is supposed to, in this case, replicate the sewer system of Rotterdam. Therefore, the name, digital twin. De digital twin of Rotterdam is very detailed and reliable and is the first of its kind. Such a 3D model is very effective for simulating certain circumstances, not only for water, and is therefore inspiring many companies to develop one of their one [13].

The script is made to simulate the water level of The Dieze with different amounts of infiltration of water in the ground. It is not a 3D script; it is a simple script meant to simulate the water levels of The Dieze. The script is written in Visualbasic and simulated in python, build under the assistance of copilot an ChatGPT. As such the script is written;

- The water level of The Dieze= The water level of The Aa+ The water level of The Dommel+ de drainage of water.
- The water level of The Aa [14]and De Dommel [15] is acquired on the sites of the local water authorities, containing the water levels of the rivers of the past time.
- This is then compared to the rainfall, which is acquired from the KNMI, Royal Netherlands Meteorological Institute [16]. With this information, the script can predict the water levels of The Aa and The Dommel with different amounts of rainfall.
- The drainage of water consists of the rainfall minus the infiltration. The model assumes that all the water from rainfall that does not infiltrate in the ground, is directly drained to the Diese.
- In this part of the script the variable is implemented. This is the amount of water that infiltrates in the ground showing the effect of infiltration on the water level of The Dieze. In ´s-Hertogenbosch 40% of the ground is impenetrable to water, says the AD newspaper [17]. This means water can infiltrate on 60% of the the ground. Following this, the script is directed to show the water levels of The Dieze with 60%,70% and 80% infiltration.

The main research about letting water infiltrate better into the ground will go as the following:

1. What are the main causes of bad water infiltration into the ground
2. What are solutions for these causes
3. How can these solutions be used in the centre of ´s-Hertogenbosch
4. How can these solutions best be applied in other cities

Results of the experiment

The script

```
import pandas as pd
from datetime import datetime

# ------------------------------------------------------------
# BESTANDSPADEN
# ------------------------------------------------------------
file_knmi = r"C:\Users\annem\AppData\Local\Programs\Python\Python313\WaterIsLife\neerslaggeg_AMMERZODEN_910.txt"
file_waterstanden = r"C:\Users\annem\AppData\Local\Programs\Python\Python313\WaterIsLife\Waterstanden Dommel 60 dagen verplaatst.

# ------------------------------------------------------------
# KNMI INLEZEN
# ------------------------------------------------------------
def read_knmi_file(filename):
    records = []
    with open(filename, "r", encoding="latin-1") as f:
        for line in f:
            line = line.strip()
            if not line or line.startswith("#") or line.startswith("STN"):
                continue

            parts = [p for p in line.replace(",", " ").split() if p]
            if len(parts) < 3:
                continue

            try:
                datum = datetime.strptime(parts[1], "%Y%m%d")
                regen_mm = float(parts[2]) / 10.0
                records.append((datum, regen_mm))
            except:
                continue

    return pd.DataFrame(records, columns=["datum", "regen_mm"])

# ------------------------------------------------------------
# WATERSTANDEN INLEZEN
# ------------------------------------------------------------
def read_excel_waterlevels(filename):
    df = pd.read_excel(filename)
    df.columns = [str(c).strip().lower() for c in df.columns]

    df["datetime"] = pd.to_datetime(df["x"], errors="coerce")
    df["dieze_peil"] = pd.to_numeric(df["y"], errors="coerce")

    df["datum"] = df["datetime"].dt.date
    df_daily = df.groupby("datum")["dieze_peil"].mean().reset_index()
    df_daily["datum"] = pd.to_datetime(df_daily["datum"])

    return df_daily

# ------------------------------------------------------------
# INLEZEN DATA
# ------------------------------------------------------------
df_rain = read_knmi_file(file_knmi)
df_rain["datum"] = pd.to_datetime(df_rain["datum"])

df_water = read_excel_waterlevels(file_waterstanden)

df = df_rain.merge(df_water, on="datum", how="left")
```

Figure 3, first part of the script

```
# ------------------------------------------------------------
# INFILTRATIE-SCENARIO'S
# ------------------------------------------------------------
df["afvoer_60"] = df["regen_mm"] * 0.40
df["afvoer_70"] = df["regen_mm"] * 0.30
df["afvoer_80"] = df["regen_mm"] * 0.20

# ------------------------------------------------------------
# DREMPELMODEL MET GEHEUGEN
# ------------------------------------------------------------
c_factor = 0.01  # 1 mm afvoer = 1 cm waterstand

def uitstroom(peil):
    if peil < 2.80:
        return 0.2  # cm/dag
    else:
        return 1.0  # cm/dag

# Startwaarden
df["dieze_60"] = 0.0
df["dieze_70"] = 0.0
df["dieze_80"] = 0.0

# Eerste dag moet een echte waarde hebben
df.loc[0, "dieze_60"] = df.loc[0, "dieze_peil"]
df.loc[0, "dieze_70"] = df.loc[0, "dieze_peil"]
df.loc[0, "dieze_80"] = df.loc[0, "dieze_peil"]

# Iteratief model
for i in range(1, len(df)):
    # vorige dag
    p60 = df.loc[i-1, "dieze_60"]
    p70 = df.loc[i-1, "dieze_70"]
    p80 = df.loc[i-1, "dieze_80"]

    # uitstroom
    out60 = uitstroom(p60)
    out70 = uitstroom(p70)
    out80 = uitstroom(p80)

    # nieuwe waterstand
    df.loc[i, "dieze_60"] = p60 + df.loc[i, "afvoer_60"] * c_factor - out60 * 0.01
    df.loc[i, "dieze_70"] = p70 + df.loc[i, "afvoer_70"] * c_factor - out70 * 0.01
    df.loc[i, "dieze_80"] = p80 + df.loc[i, "afvoer_80"] * c_factor - out80 * 0.01

# ------------------------------------------------------------
# EXPORT
# ------------------------------------------------------------
df_out = df[[
    "datum",
    "regen_mm",
    "afvoer_60", "afvoer_70", "afvoer_80",
    "dieze_peil",
    "dieze_60", "dieze_70", "dieze_80"
]]

df_out.to_csv("dieze_model_dommel_60dagen_drempel_60_70_80.csv", index=False)

print("CSV-bestand 'dieze_model_dommel_60dagen_drempel_60_70_80.csv' is aangemaakt.")
```

Figure 4. second part of the script

The outcome of the script is shown in a graph, which is shown in figure 5. The x-as contains the date and the y-as contains the water level of The Dieze with 60%,70% and 80% infiltration.

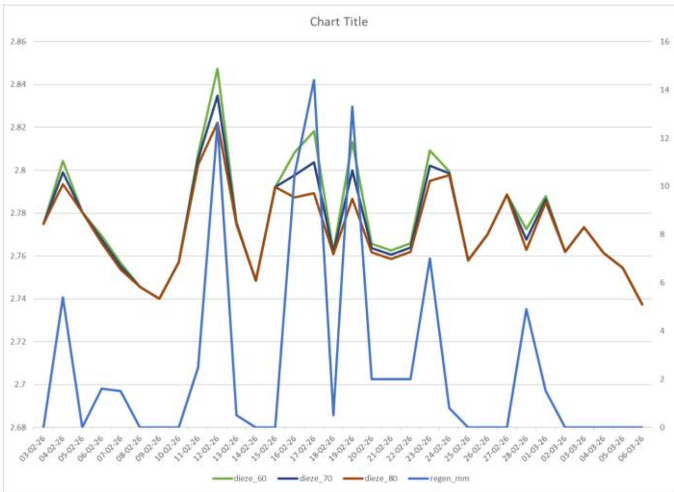

Figure 5, the graph of the script

This graph shows four lines. As indicated at the bottom of the graph, the blue line represents rainfall, while the other three lines represent the water levels of the Dieze under different infiltration scenarios. The green line represents the original water level of the Dieze with 60% infiltration, the dark blue line represents 70% infiltration, and the red line represents 80% infiltration. During periods of heavy rainfall, the peak water level is lower for the red line than for the green line. However, the original script showed that the lines became uniform again almost immediately after the peaks. This should not occur, or at least not so quickly, because differences in peak water levels should continue to influence the subsequent water levels. To address this issue, a "threshold method" was implemented using AI assistance. With this method, the script takes into account that water levels decrease at different rates for each scenario. This can be observed in the first peak, where the red line drops first, followed by the dark blue line after some time, and finally the green line. This distinction is particularly important during extended periods of heavy rainfall, because the peak water levels become lower and the water levels decrease more rapidly. As a result, the overall water level remains lower, which reduces the risk of flooding. It could be argued that lower water levels are disadvantageous during dry periods. However, this effect is mitigated by the fact that lower water levels occur because less water is discharged into the river system. Instead, more water infiltrates into the ground, which helps reduce the effects of drought.

It could be noted that the datasets used in the script are not fully compatible. The data that shows the water levels of the rivers are relatively recent, whereas the rainfall data comes from an earlier period. As a result, the script cannot directly compare the two datasets in their original form. To make the data match, the river water level data in the script were purposely shifted 60 days earlier so that they aligned with the rainfall dataset. Because of this, the resulting graph is not fully accurate from a temporal perspective. For example, the first peak in water level looks higher than the second peak, despite there being more rainfall in the second peaks. This inconsistency is caused by the mismatch between the datasets rather than by the hydrological script. Although the script does not produce accurate results, it still effectively shows the positive effects of increased water infiltration.

The problems

The main cause of bad water infiltration into the ground is the large amounts of impenetrable surfaces where water cannot pass through. Streets are paved with stone; parking places are paved with stones and house are impenetrable to water. All the water coming from these places will be redirected to the sewers. This all puts heavy strain on the sewers.

The solutions

-grass-paving slabs

Grass-paving slabs are concrete paving with holes through which grass can grow, allowing water to infiltrate; these holes do not need to be large to still allow an infiltration rate of up to 100% of the soil [18]. Thanks to the small holes, often around 5 cm in diameter, vehicles can still drive over them, making them perfect for driveways and car parks.

-Permeable paving.

Permeable paving is a relatively new and innovative type of paving and asphalt that allows water to flow through easily and thus infiltrate. This paving comes in all shapes and sizes, so it can be used anywhere. However, the passthrough rate of permeable paving is heavily dependent on how well it is maintained. Newly installed paving has a passthrough rate of over 4,000mm/hr/m2 with an average of 400 mm/hr/m2 [19], however, without proper maintenance this could lower to 50mm/hr/m2 [20].

-City Parks

City parks such as the recently constructed Burgemeester Loefplein are a good solution to the problem of insufficient infiltration in the city centre [21]. By replacing paved city squares with parks, water can infiltrate and the city centre looks greener.

-**Disconnecting rainwater pipes from the sewer system**

By disconnecting rainwater pipes that are connected to the sewer system, rainwater falling on roofs can be guided to the soil to infiltrate [22], rather than run off via the sewer, relieving pressure from the sewage system.

-Underground buffers.

Underground water buffers can be used to temporarily store rainwater, thereby relieving pressure on the sewer system; this water can then still gradually infiltrate later, causing the soil to absorb it better [23].

-Green gardens and roofs

green roofs hold on to rainwater, reducing pressure on the sewer system during heavy rainfall. [24]
By replacing stone gardens with green gardens, more rainwater can infiltrate [24].

How can these methods be applied to the city centre of 's-Hertogenbosch?

We wish to lay grass-paving slabs in the following car parks:
- the car park behind Basic Fit. **(1)**
- the two car parks near St Catharina's Church **(2)**
- the car park on Prins Bernhartstraat **(3)**

Grass-paving slabs are a cost-effective way to allow more water to infiltrate the ground. Car parks are the perfect place for this because there is little foot or cycle traffic.

in the city centre of 's-Hertogenbosch, there are no further opportunities for creating urban parks such as Burgemeester Loefplein **(4)** and the Canal Park **(5)**, which is currently under construction. For this reason, there is no need to create any more urban parks in the centre of 's-Hertogenbosch.

By disconnecting rainwater pipes from government buildings such as schools and the town hall from the sewer system, rainwater falling on these buildings can infiltrate, whilst reducing the pressure on the sewer system. The city council could also offer subsidies to residents and businesses for disconnecting their rainwater pipes.

Underground water buffers are a good way to temporarily store water, allowing it to infiltrate later or be discharged via the sewer system. In the city centre of 's-Hertogenbosch, Amadeiroplein **(6)** is the best location for a water buffer, because this small square lays right in the heart of 's-Hertogenbosch and currently transports a lot of rainwater from surrounding streets and rooftops to the sewer. By installing a large water buffer beneath this area and channelling rainwater from the surrounding streets towards it, the current heavy pressure on the sewer system during heavy downpours will be reduced.

By offering residents a subsidy to remove the paving stones from their gardens and replace them

with grass or other plants, rainwater can infiltrate these gardens.
By paving the two largest squares in 's-Hertogenbosch, the Parade **(7**) and the Markt **(8)**, with permeable paving, a large proportion of the rainwater falling on those squares will easily infiltrate the ground; this alone will make a significant difference to the pressure on the sewer system. For the locations of these changes, see the map

roofs greener, much more water can infiltrate. This will reduce water nuisance as it takes a lot of pressure off the sewer system.

Our advice for people who want to carry out a similar study: The script used in this study is not fully accurate. This is partly due to the mismatch between the datasets, but also because the model itself is relatively simple. For example, the script assumes that all water that does not infiltrate into the ground is directly discharged into the rivers. In reality, this process is more complex due to factors such as buffer zones, temporary water storage, and delayed discharge processes. However, the primary purpose of this research was not to develop a highly detailed hydrological model of the local rivers. Instead, the script was built with the intent to show the positive effects of water infiltration on river water levels. Therefore, for future research it may be more effective to focus less on modelling specific local rivers and instead develop a more detailed, generalized and reliable hydrological model. This would allow the research to focus more clearly on demonstrating the effects of water infiltration on water levels, rather than replacing the local water system as accurate as possible. Furthermore, a similar study could do tests to determine the effectiveness of the measures described in our research paper.

The best ways to apply these methods for other Dutch city centres

This study focuses specifically on 's-Hertogenbosch and therefore does not make any definitive statements about the effectiveness of these measures in other cities, as local factors such as soil composition, urban layout and water management can vary significantly. However, the results do show that the measures used are relatively simple and flexible to implement. Consequently, the findings of this study offer valuable insights for other cities facing similar problems, both in the Netherlands and potentially beyond, provided that additional local research is carried out.

Conclusion

The main cause of water nuisance in the centre of 's-Hertogenbosch is insufficient water infiltration, which leads to the sewer system becoming overloaded. Our research shows that by changing the paving in squares and car parks, constructing an underground water buffer, creating urban parks, disconnecting downpipes and making gardens and

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The Catalan Sponge:

Potential measures to tackle a drought in Catalonia in 2040

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Abstract

Although Catalonia was declared drought free in 2025, water scarcity is still an ongoing concern for the future that affects all of its population. This research project analyses the effectiveness of the Catalan government in tackling the 2021-2024 drought, as well as how other drought-prone regions, particularly California, have managed theirs. Furthermore, it proposes a new drought plan designed for a possible drought in 2040, based on insights from interviews with experts in the field. This study will look at both infrastructure measures and recommendations for the general public, so as to be able to adapt quicker to future water crises.

Keywords:

Catalonia, 2040, drought, water management, sponge city model.

1.Introduction

1.1 Motivation

If one looks at water as more than just a chemical structure, it is evident that its impact goes much further than just creating life. Without water there is nothing, no culture, no society. There is evidence of this all throughout history: all primitive societies were established near rivers or lakes and then later evolved into big cities with ports. These ports have been the nuclei of human society from the days of Marco Polo to today's Suez Canal. Clear examples of the importance of water in metropolitan areas is that almost all capital cities are built along some body of water. We see a few exceptions such as Tehran, but even the Iranian government is considering moving their capital to cities nearer to water due to a severe water crisis. Another example is Seville which lost its commercial importance when its waterway got too shallow.

Thus water is so much more than just a chemical compound. But what happens when there is no water left? What will become of human society? This has been a growing concern in drought prone countries for many years now. One of the many cities affected is Barcelona, which has already experienced a 6-year long drought in this decade. The goal of this project is to analyse and improve the measures that are taken by governments to address this climate change effect.

Our hypothesis is that if measures similar to those applied during the 2021-2024 drought in Catalonia are taken, improving them with long-term strategies and adapting them to 2040 conditions, it will be possible to significantly reduce the effects of future droughts on the water supply and the population.

1.2 Research objectives

1. Analysis of Past Measures (2018–2024)

Objective 1.1: Quantify the contribution of reservoirs, desalination plants (El Prat, Blanes), and regenerated water to the Barcelona Metropolitan Area's supply during the 2018 and 2021–2024 droughts.

Objective 1.2: Analyse the implementation and limits of drought measures, including the "Pla Especial de Sequera" (Special Drought Plan), the drought traffic light system and sectoral restrictions, and assess their effects on urban and agricultural water users.

2. Understanding of past droughts and how water management works

Objective 2.1: Characterise droughts in Catalonia, including their types (meteorological, hydrological, agricultural and socioeconomic) and monitoring indicators (SPI, reservoir levels, groundwater piezometers).

Objective 2.2: Review the Catalan water management system, including institutional responsibilities (ACA, Ebre Hydrographic Confederation), current infrastructure (reservoirs, desalination and water reuse plants), and the role of social and economic measures in managing scarcity.

Objective 2.3: Examine comparative international experiences, particularly the 2020–2022 California drought, including technological solutions (recycled water, desalination, groundwater recharge), management strategies and lessons applicable to Catalonia.

3. Proposal and Planning for 2040

Objective 3.1: Conduct interviews with water management experts to understand professional perspectives, technological possibilities and social considerations for future drought management.

Objective 3.2: Use insights from expert interviews, climate projections and past drought analyses to elaborate a 2040 drought management plan for Catalonia, integrating infrastructure, policy and social strategies.

1.3 Methodology

The methodology of this project is twofold: the research part, dedicated to gathering data and aiming for expertise on the topic, and a practical part, focused on designing a strategic plan for a possible drought in Catalonia in 2040.

The first step is to create a research frame by collecting and analyzing strategic data from official sources to understand the present, the future and the past of water in Catalonia. We search for data on the climatic conditions of Catalonia using the IPCC and TICCC reports, and we identify the climate baseline for 2040. This allows us to work with realistic numbers. We analyse the Special Drought Plan (PES) from the ACA to understand how the Catalan government is preparing to face the hypothetical droughts in the future. The 2018 drought data will also be analysed by looking at the data from Meteocat and Observatori Fabra to see why that crisis was solved quickly compared to the 2021-2024 period.

The next step is to understand how to produce "new water". For this step, we will study reports from ATL and Aigües de Barcelona regarding desalination (ITAM) and water reclamation (ERA). We will specifically look at the Llobregat river strategy to learn how recycled water can be safely added back into the supply system.

Following this, there is the practical work that is based on interviews with a meteorologist and other experts to help design clear goals and measures to minimise drought risks for 2040. Finally, we will design a campaign to be able to share our findings with the public and try to raise awareness on the issue.

2.Theoretical framework

2.1 Climate change and the Mediterranean

2.1.1 The global climate crisis

The current global climate crisis is characterised by a seemingly unstoppable increase in average temperatures due to the accumulation of greenhouse gases in the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC) in its sixth assessment report (AR6), the Earth's surface temperature has risen by approximately 1.1ºC since the pre-industrial period (1850-1900). **[1]** This phenomenon, mainly driven by human activity, has altered the global hydrological cycle, leading to more extreme natural disasters, including prolonged droughts and intense heatwaves. **[1]**

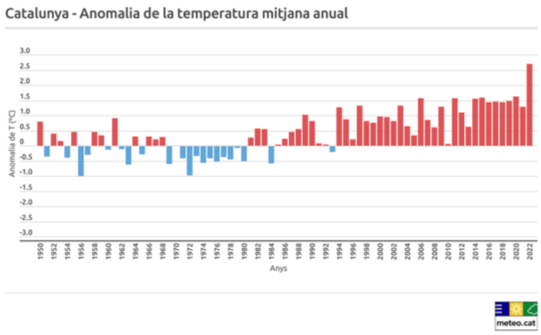

Figure 1. Global temperature change and climate trends. Note. The visual illustrates the increase in global temperature associated with greenhouse gas emissions. [1]

2.1.2 Climate change in the Mediterranean:

The Mediterranean region is uniquely vulnerable, so much so that scientists have defined this region as a ''climate change hotspot'' because it is warming much faster than the global average. **[1, 6]** While the world aims to limit warming to 1.5ºC, the Mediterranean has already reached this threshold in many areas. **[1, 6]**

The geographic characteristics of the Mediterranean, a semi-closed sea surrounded by diverse environments, amplify the effects of climate change. For Catalonia, this translates into a tropicalization of its climate, where rainfall becomes more irregular, and the periods between rainy seasons grow longer and more severe. **[6]**

2.1.3 Specific projections for Catalonia

By 2040, Catalonia will face a challenging climatic scenario based on the data provided by the Third Report on climate change in Catalonia (TICCC) and the Meteorological Service of Catalonia (Meteocat).

The key projections indicate the following:

Precipitation deficit:

Precipitation projections for Catalonia are not as reliable as temperature projections, since rainfall has more variability. In spite of this, there is a general tendency towards a decrease in precipitation, which would be most significant in summer across the whole country, especially in coastal areas. **[9]** However, the main challenge is not just the lack of water, but its distribution; rain is expected to fall in shorter, more violent episodes (flash floods), which do not allow for efficient soil infiltration or reservoir recharging. **[9,10]**

Increased drought duration:

The maximum length of consecutive days with precipitation below 1mm is projected to increase on a regional scale (Catalonia). This will make droughts more intense, especially across the coastal and pre-coastal zone. **[9]**

Increased Evapotranspiration:

Higher temperatures lead to higher rates of water loss from plants and soil. Combined with reduced precipitation, the demand for water in agriculture and natural ecosystems increases significantly, further depleting the available "blue water" (rivers and aquifers). **[4, 2]**

2.2 Characterization and types of droughts

2.2.1 Drought definition

Droughts are natural, recurrent features of the climate, characterised by a temporary lack in water availability compared to the statistical average of a specific region. Unlike aridity, which is a permanent climatic trait, drought is a deviation from the norm.

In the Mediterranean context, droughts are increasingly influenced by "flash droughts", episodes that intensify rapidly due to high temperatures and low humidity. (IPCC AR6) **[4]**

2.2.2 The four stages of drought:

To be able to understand the effects of past droughts and get an accurate picture of what future ones would look like, it is essential to distinguish between the four categories of drought that explain the gravity of the situation. **[11]**

1.Meteorological Drought

This is the primary stage and is defined by a significant decrease in precipitation over a specific period of time. Its impacts are highly dependent on the season, time of year and climate variability. **[11]** It is usually measured using the Standardized Precipitation Index (SPI), which quantifies the precipitation deficit. **[12,4]**

2. Hydrological Drought

This occurs when the lack of rain begins to affect surface and subsurface water levels. It is reflected in the declining volumes of reservoirs, rivers and aquifers. **[11]** There is usually a time lag between the meteorological and hydrological stages, meaning that even after rainfall returns, water bodies may take months or years to recover. **[11]**

3. Agricultural or Ecological Drought

This stage is reached when soil moisture becomes insufficient to maintain crops or natural vegetation, directly threatening food production and natural ecosystems. **[11]** It is typically measured using the Palmer Drought Severity index, which accounts for both precipitation deficits and evapotranspiration quantity. **[4,12]**.

4.Socioeconomic Drought

This is considered the most severe stage, which occurs when water shortages start to affect the health, well-being and economic activities of the population (industry, tourism and domestic supply). **[11]**.

This is the stage that the Catalan Sponge measures will aim to prevent.

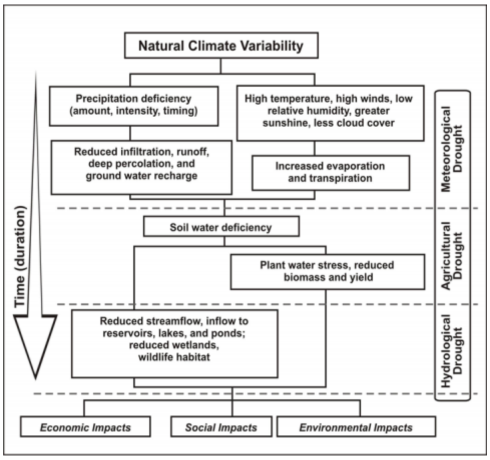

Figure 2. Sequence of drought occurrence and impacts for commonly accepted drought types. Note. The diagram shows how meteorological drought can develop into agricultural, hydrological and socioeconomic impacts.

2.2.3 Indicators and thresholds for drought monitoring

In Catalonia, the management of water resources during drought periods is governed by the Special Drought Plan (PES). **[12]** This plan establishes an objective monitoring system based on several key indicators that allow authorities to act before the situation becomes irreversible. **[12]**

2.2.4 The standardized precipitation index (SPI)

The SPI is the international standard for measuring the meteorological drought. It quantifies the precipitation deficit for different time scales (typically 3, 6, 9 and 12 months). **[12]**

Positive SPI values indicate that precipitation is greater than average, while negative values indicate below-average precipitation. When the SPI falls below -1.5 or 2.0, the region is considered to be in a "severe or "extreme meteorological drought". **[12]**

2.2.5 Reservoir levels and groundwater piezometers

For hydrological drought, the ACA monitors the state of reserves in the Internal Basins of Catalonia (the Ter-Llobregat system, Muga, Foix, and others). **[12]**

Surface water is measured as a percentage of the total capacity of reservoirs such as Sau, Susequeda and La Baells, while groundwater is monitored via piezometers that monitor the depth of water tables in aquifers (upper level in unconfined aquifers). **[12,15]**

2.3 Water management system in Catalonia

2.3.1 Institutional framework and water governance

Water management in Catalonia is mainly led by the Catalan Water Agency. This public sector is responsible for the planning, control and management of water resources within Catalan territory, especially in situations of water scarcity. **[12]**

Hydrologically, Catalonia is divided into two major management areas. On the one hand, the **Internal Basins of Catalonia (CIC)**, which include rivers such as the Ter, Llobregat, and Besòs, are managed directly by the ACA. On the other hand, the basins that belong to the **Ebre River Basin** are managed by the **Ebre Hydrographic Confederation (CHE)**, a state-level authority. This division results in different water management approaches depending on the territory. **[15]**

2.3.2 The drought status system (Traffic light system)

Once activated, the Special Drought Plan defines six scenarios by six colours, representing the different states across the eighteen areas into which the internal basin territory of Catalonia is divided. During each state, different legal restrictions are activated to conserve maximum water, depending on the water reservoir levels. **[12,13]**

The thresholds and key measures are the following **[12,13]**

1.**Normalcy (Blue):** No drought conditions exist and therefore no restrictions exist.

2.**Pre-alert (Green):** It is declared when reserves fall below 60% and there is evidence of a possible drought. Preventive measures are activated including more active monitoring and awareness campaigns for the public, but no mandatory restrictions exist.

3.**Alert (Yellow):** It is generally declared when reserves drop to 40%, and includes more restrictive measures for irrigation, industry and recreational use.

4. **Exceptionality (Orange):** It is declared when reserves fall below 25% and therefore increases desalination production to 75-100%. Irrigation in both public and private green spaces is prohibited if using potable water.

5. **Pre-Emergency (Pink):** This is a new stage that was included in the 2021-2024 drought to make transition easier for a declaration of emergency.

6. **Emergency (Red):** This final stage is triggered when the reserves are below 16%. For the 2021-2024 crisis, this included various restrictions in agricultural irrigation, industrial uses and for general citizens.

Present water status (9/05/2026):

Estat	Municipis
Normalitat	630 (100%)
Prealerta	0 (0%)
Alerta	0 (0%)
Excepcionalitat	0 (0%)
Preemergència	0 (0%)
Emergència	0 (0%)

Figure 3. Current drought-status distribution in Catalonia on 9 May 2026. Note. The chart summarises the drought-status categories used in the Catalan Water Agency traffic-light system.[14].

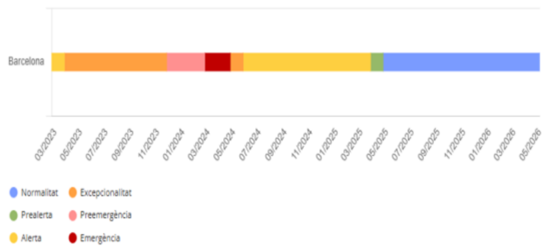

Figure 4. Timeline of drought traffic-light stages in Barcelona from March 2023 to May 2026. Note. The timeline shows changes between normality, pre-alert, alert, exceptionality, preemergency and emergency phases. [14]

2.4 Historical analysis of the 2018 drought and the 2021–2024 crisis

2.4.1 2018 drought analysis

The 2018 episode is often categorised as a "meteorological scare." Although it triggered the activation of the Special Drought Plan (PES), its duration was insufficient to really test Catalonia's management capacity. **[14]**

By the beginning of 2018, the Ter-Llobregat system was at 43-45% capacity. The lack of snow in the Pyrenees during 2017-2018 winter intensified concerns for the irrigation season. **[14]**

During this period, the El Prat desalination plant (ITAM Llobregat) was only used as a backup, operating at approximately 20-30% of its capacity. The cost of desalination remained a significant concert for the administration at the time. **[16]**

Looking at the impacts it had in comparison to what was to come, they were pretty minimal and mostly limited to the Muga basin for agriculture while there were no restrictions on urban supply. **[12]**

One element that was very unique to this brief crisis that later solved the issue was "the May rain" effect. The start of 2018 was extraordinarily rainy in Barcelona, with a total of 337 litres per square metre. **[16]** This exceptional rainfall led to a rapid recovery, creating a false sense of security leading to the postponement of investments in water reclamation plants (ERA). **[16]**

2.4.2 The 2021-2024 crisis:

The period between 2021 and 2024 caused a complete transformation of the Catalan water model. This crisis is considered the most severe since droughts were recorded (1916), not only because of the lack of rain but also because of the record-breaking high temperatures. **[19]**

2.4.3 Timeline

Unlike other droughts, this drought saw a much slower decline in water capacity that lasted more than 40 months. **[19]**

From January 2021 onwards, the accumulated precipitation was significantly below the historical average, generating "water stress" that was felt across all sectors. It was especially striking since it was just after a very rainy year (2020), and felt like a sudden stop in precipitation, causing a steady decline in reservoir levels. **[19]**

During the years 2022-2023, Catalonia experienced the hottest years in history. This meant that the little water left in the reservoirs evaporated faster, adding to the fact that crops and soil needed more water than usual. **[19]**

In February 2024 the Catalan Government declared the emergency phase of the Special Drought Plan for the Ter-Llobregat system, covering 202 municipalities. **[26]** This is a key date since it included many new restrictions that had never been implemented before. They were still active until late June, when it started raining again. **[22]**

2.4.4 Impact of natural resources

Before 2021, Catalonia really only depended on rain and snowmelt for water resources, that is why when these natural resources ran out, the drought intensified massively.

The Sau Reservoir:

The Sau Reservoir (Pantà de Sau) is a massive reservoir located in Barcelona which provides water to Barcelona, Girona, the Costa Brava as well as generating energy for the region. It was created by a damming of the river Ter in the 1960s. **[23]** When the water was dammed, it flooded an abandoned town called Sant Romà de Sau that contained an ancient Romanesque church dating back to 1061. **[24]** The reservoir covers the entire town, including this church. When the water levels are low, you can see the spire of the church. During the 2021-2024 drought, the entire Sau church was completely visible, since the reservoir was only

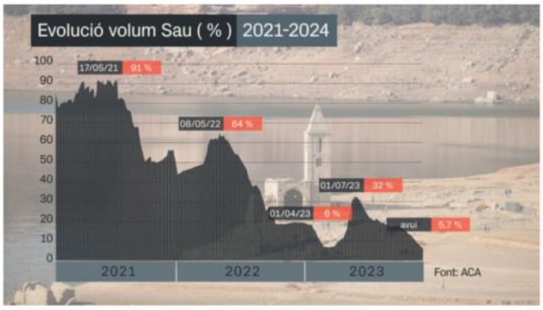

Figure 5. Evolution of water volume in the Sau Reservoir during the 2021-2024 drought. Note. The image combines reservoir-level data with photographs of the Sant Romà de Sau church as water levels fell. [22]

at 5,61% capacity (9,53 hm3), as seen below. **[22]**

Lack of snowfall and snowmelt:

In the winters of 2022 and 2023, there was almost no snow in the Pyrenees. This meant that during the spring, there was no natural recharge for the rivers worsening the effects of drought. **[20]**

Without this seasonal thaw, the Ter and Llobregat rivers lacked their primary source of natural recharge, causing reservoir levels to drop drastically before the summer months. This absence of snowmelt essentially forced a faster transition to emergency scenarios than just lack of precipitation. **[19]**

Looking toward 2040, it is suggested that this lack of snow will not be an occasional event but a recurring one. Rising temperatures cause a rise in the snowline, meaning it must be much higher up the mountains for snow to settle.

Furthermore, increased evapotranspiration means that the little water that does melt is often absorbed by the dry earth before it can ever reach the reservoirs, reducing the efficiency of the natural water cycle. **[1, 8]**

2.4.5 Social and economic impact

The 2021-2024 drought was a perfect example of a socioeconomic drought because it forced the government to make very difficult decisions that affected every sector of Catalan society. **[12]**

Agriculture impacts:

Looking at it from the farmers' point of view, they seem to have been the sector that suffered the most. In many areas, they faced an 80% reduction in water for irrigation and 50% for livestock uses. **[21, 26]**According to JARC, this led to the loss of thousands of hectares of crops and cereals, and therefore government compensations and financial assistance. **[25]**

Industrial impacts:

The industrial sector was also severely restricted. Industrial water users faced a mandatory 25% reduction in water consumption, which greatly affected production capacity and operational costs across multiple industries. **[26]**

Impacts on general citizens:

One of the most striking restrictions was that for the first time, general citizens' water use was also limited. This happened when Catalonia found itself in the emergency scenario threshold, where the population was limited to 200 litres per person per day. This however included both domestic consumption, economic activities and municipal uses, so that the amount recommended was actually closer to 90 litres for households. **[26]** Other limitations included the prohibition of vehicles being cleaned with non-recycled water, as well as the use of drinking water for recreational activities, and the closure of public showers at the beach. **[26]**

2.4.6 Key lessons for 2040

The main takeaway from this drought period for both the government and the general population is that rain is no longer a reliable source of water.

It especially brought to light that the current reservoirs are too small for such long droughts, that there needs to be a drastic increase in the capacity of water production (desalination and recycling), and that the agricultural sector will not be able to survive 2040 if it only relies on rivers. **[12, 19]**

2.5 Current water infrastructure in Catalonia

2.5.1 Reservoirs

Reservoirs constitute the core of the water storage system in Catalonia and are a key indicator for assessing drought conditions. They regulate river flows and ensure water supply for domestic, agricultural and industrial uses during periods of low precipitation. **[12]**

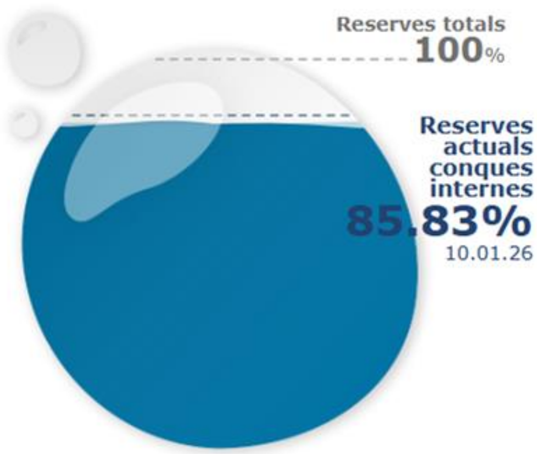

Figure 6. Water reserves in Catalonia's internal basins on 10 January 2026. Note. The chart shows reservoir storage as a percentage of total capacity. [14]

According to official data from the ACA, published by the Government of Catalonia, current water reserves in the internal basins stand at **85.83% of total capacity** as of **January 10, 2026**. (ACA, AETR) This figure, shown in the accompanying graph, indicates a relatively favourable situation compared to the historical minimum levels recorded during the 2021–2024 drought crisis.

Despite this high level of reserves, water authorities emphasise that this indicator cannot be interpreted on its own. Actual water availability also depends on factors such as future rainfall regularity, increased demand, and the impact of evapotranspiration associated with rising temperatures. **[12]** For this reason, the drought traffic light system remains essential for anticipating potential risk scenarios, even in apparently positive contexts. **[13]**

2.5.2 Reservoir levels and drought management decisions

Reservoir levels are one of the main criteria used to determine changes in drought scenarios within the Special Drought Plan. When reserves decrease steadily, the system may progressively shift from normality to pre-alert, alert or more severe scenarios, triggering sectoral restrictions. **[12, 14]**

Therefore, the information provided by graphs such as this one is not only descriptive but also strategic, as it enables authorities to make informed decisions to ensure water security. **[12]**

2.5.3 Desalination and reclamation process

Desalination and water reclamation are two relatively new types of technology that Catalonia relied on heavily during the 2021-2024 crisis, which ultimately saved the region. During the crisis, the following sources became the primary suppliers:

Desalination (ITAM):

Catalonia has two main functioning desalination plants or ITAMs (Instal·lació de Tractament d'Aigua Marina): El Prat de Llobregat and Tordera, which have been operating at their maximum capacity for years. El Prat de Llobregat is actually the biggest urban supply water plant in Europe and produces up to 60 hm3/year. **[27]** The Tordera ITAM can only produce up to 20 hm3/year. **[18]**

The water is first captured from the coast and put through pipes that connect to pretreatment, called flotation, which consists of 3 types of filtering, including “open” (basic), “closed” (pressurised) and finally through cartridges. Then it goes through a system of reverse osmosis membranes, that is the finest filtering that removes 99% of contaminants. To reach the standard for drinkable water, the filtered water has to be remineralised and passed through carbonated càlcic. Usable water is sent to the deposits in Fontsanta while the waste is returned to the sea after being combined with residual water from the Baix Llobregat purifier. **[17]**

Figure 7. Infrastructure and distribution map of the El Prat de Llobregat desalination plant. Note. The visual identifies the main treatment and supply areas connected to the Ter-Llobregat water network. [17]

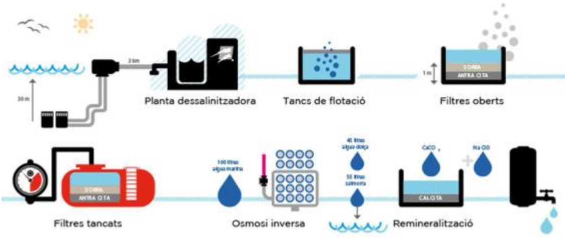

Figure 8. Desalination treatment process at the El Prat de Llobregat ITAM. Note. The schematic shows seawater capture, pretreatment, reverse osmosis, remineralisation and distribution to the Fontsanta reservoirs. [17]

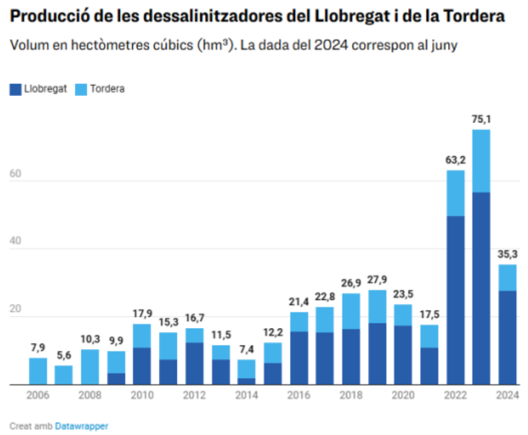

Figure 9. Annual production of the Llobregat and Tordera desalination plants. Note. Values are expressed in cubic hectometres and show the rising contribution of desalination during drought years. [44]

Water reclamation (ERA):

Water reclamation is another alternative for water production; it goes through a similar process to desalination including preliminary physical and chemical filters, and reverse osmosis filtering. **[28]** Depending on what the water will be used for, it will either be discharged at this moment (street cleaning, irrigation, industrial use) or sent on further for potabilisation. That reclaimed water is then discharged into rivers such as the Llobregat, which later is collected at the Drinking Water treatment plant in Sant Joan Despí, where it is purified. **[15]**

Figure 10. Current and planned wastewater, reclaimed-water and drinking-water distribution in metropolitan Barcelona. Note. The map shows the connection between the Baix Llobregat reclamation plant, the Llobregat River and the Sant Joan Despí drinking-water treatment plant. [15]

As of 2026, Catalonia has 24 of these water reclamation stations **[29]**, but the biggest and most impactful is the Prat del Llobregat plant, so much so that Barcelona has been relying on it since 2009. **[15]**

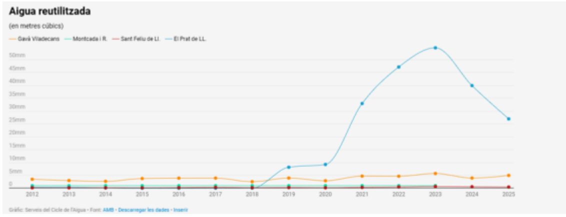

Figure 11. Estimated operational costs of traditional, reclaimed and desalinated water sources. Note. The comparison includes maintenance, labour and energy consumption per cubic metre. [30].

It is important to note that Catalonia should not simply use this water directly as a substitute, but that it should be used to refill and recharge aquifers and basins to help maintain an ecological balance. **[15]**

2.5.4 Costs of water infrastructure

Above, a detailed projection of the cost of each method **[30]**:

Source	Maintenance and labour	Energy consumption	Total OPEX (operational expenditure) per m3
Traditional (Rain)	0.04 €	0.05 €	0.09 €
Reclaimed (ERA)	0.08 €	0.14 €	0.22 €
Desalinated (ITAM)	0.15 €	0.65 €	0.80 €

2.5.5 Digital water management

Beyond physical infrastructure, in the 21st century a lot of water management is done through digital tools. One of the main new technologies being rolled out in Catalonia are smart meters. These act as kinds of remote trackers that transmit real time consumption data and possible leaks to Aigües de Barcelona. This has been implemented since 2020 but only across the Barcelona Metropolitan Area. **[31]**

This is particularly important since Spain's water distribution networks lose approximately 23.5% of water supply due to leaks and breaks. **[32]**

Another emerging technology is the "digital twin", a new tool that simulates an exact replica of a physical system, which can help monitor and predict issues. The CEAB-CSIC and ACA are currently developing digital twins to analyse water quality variables in Catalonia's internal basins. **[33]**

Finally there is also another project being piloted in El Prat de Llobregat, a small municipality in Catalonia. It was deployed by Adasa Sistemas, which used acoustic sensors across the drinking water network and AI to detect and locate leaks by analysing water pressure in pipes. **[32]**

2.6 The 2020-2022 Californian drought

Droughts are very subtle and have gradual effects so it is hard for cities to date exactly when they started.

California, similar to Barcelona and the rest of Spain throughout history, has always been more susceptible to droughts, but with the appearance of climate change the number and severity of these has increased notably. The state has experienced many droughts, but its most recent was from 2020 to 2022 which coincided with the highest temperatures ever recorded. **[34]**

California has a similar Mediterranean climate to Catalonia: hot and dry summers and mild winters. There are variations in this due to El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO). These natural climate patterns are responsible for periodic fluctuations in precipitation that greatly affect California. **[34]**

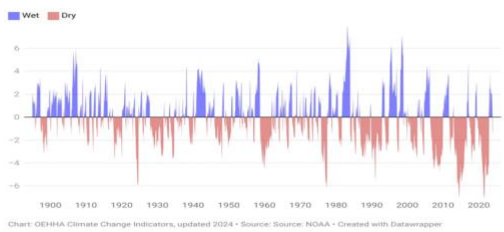

Figure 12.

Temperature and precipitation patterns during the 2020-2022 California drought. Note. The graph contextualises the drought period through temperature and precipitation anomalies. **[34]**

2.6.1 California's water supply strategy:

Between the years 2021 and 2025, the governor of California, Gavin Newsom, had planned to invest $5.1 billion in both drought and flooding infrastructure. The budget included both investments to support safe drinking water, water supply and reliability and flood resilience, immediate drought support and nature-based solutions. **[35]**

The main goals of this plan were to: create storage space for up to 4 million acre-feet of water, recycle and reuse at least 800,000 acre-feet of water per year by 2030, free up 500,000 acre-feet of water through more efficient water use and conservation and to make new water available for use by capturing stormwater and desalinating ocean water and salty water in groundwater basins. It also aimed to improve forecasting, data and management, including the modernisation of water rights. **[36]**

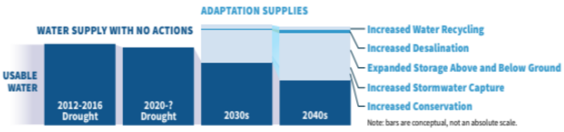

Figure 13. Main goals of California's Water Supply Strategy. Note. The infographic summarises water-storage, recycling, conservation, stormwater-capture and desalination objectives. [36]

2.6.2 Measures in California's Water Supply Strategy:

California has identified and supported specific recycled water projects to help reuse wastewater instead of discharging it into the ocean. **[36]**

1. **Recycling water legislation**

- The State Water Board is working with local agencies to identify recycled water projects that could be operational by 2030 and no later than 2040. **[36]**
- Formation of the Recycled Water Strike Team, which convenes to resolve permitting and funding obstacles for planned projects. **[36]**

2. **Brackish and Seawater Desalination Steps**

- Review groundwater basins for volumes available for brackish groundwater desalination. **[36]**
- Develop siting criteria to streamline permitting for future seawater desalination facilities. **[36]**

3. **Expanded Groundwater Recharge**

- 4.1 million acre-feet of managed groundwater recharge was achieved in 2023, increasing overall groundwater storage significantly. **[37]**
- The state issued executive orders and streamlined permitting to expand recharge capacity. **[35]**

2.7 Sponge City model (Shanghai)

The sponge city model is a new way of looking at water infrastructure, it was originally designed by landscape architect Kongjian Yu in 2013. **[38, 40]** The concept is based on creating an urban planning model that goes beyond traditional infrastructures (grey infrastructure) by integrating nature-based solutions. **[39]** The goal is to make a city act like a sponge that absorbs, filters, stores and purifies water instead of letting it go into sewers or cause floods. **[38]**

2.7.1 Design principles:

In October 2014, the Chinese Ministry of Housing and Urban Rural Development published the "Technical Guidelines for Sponge City Construction" as the major framework for the programme. **[40]**

The "sponginess" is measured by looking at the amount of blue and green infrastructure in contrast to grey infrastructure, as well as water retention capacity and plant life. **[38]**

To replicate the function of a sponge, the technical elements have been divided into 6 different uses **[40]** :

Infiltration: Replacing waterproof concrete with permeable pavements to recharge groundwater.

Detention: Creating green spaces that slow down the flow of water.

Storage: Using rain gardens, wetlands and underground cisterns to hold water.

Purification: Using plants and soil to naturally filter pollutants from runoff.

Utilization (reuse): Using the stored water for irrigation, street cleaning or fire-fighting.

Discharge: Ensuring that during extreme events, excess water is discharged safely.

2.7.2 Case study

Lingang New City, is a city in Shanghai's Pudong district that was selected as a pilot sponge city by the government in 2016. It currently serves as China's largest sponge city pilot zone. **[41]**

Some of the most important changes were the 36 kilometres of roads that were replaced with water absorbent bricks, the creation of artificial wetlands (see image), construction of water storage units, grass areas in parking lots and underground water pools in existing gardens. **[41, 42]**

This results in a system that can purify up to 15,000 cubic meters of water per day and can collect and utilise 70 percent of its rainwater, and has significantly reduced its flood risks, which was the original goal set by the Chinese government. **[42, 43]**

Figure 14. Lingang New City as a sponge-city pilot zone in Shanghai. Note. The image illustrates blue-green infrastructure used to absorb, store and reuse stormwater. [41]

2.8 Projections of future scenarios for 2040

The global projections for the climate's future are designed by the IPCC (Intergovernmental Panel on Climate Change). They present two general climate scenarios based on GHG (Greenhouse gas emissions): RCP4.5 (intermediate) and RCP8.5 (severe). **[1]** Precipitation projections for Catalonia are hard to make since there is a lot of variability due to the Mediterranean climate. Although uncertain, it is expected that there will be a general decrease in average annual precipitation. **[9]**

2.8.1 Meteocat scenario (RCP4.5)

The RCP4.5 scenario assumes that the 2015 Paris Agreement emission reduction targets are achieved. This would still mean that the GHG would still be higher than in 2025, but projects that after 2030, emissions would reduce, causing only a rise between 1.5°C and 2.4°C above pre-industrial levels by the end of the century **[1]**

For Catalonia this would mean similar trends as right now, such as a decrease in annual precipitation, more intense rainfall although less frequent, increased drought frequency and overall higher temperatures that will cause increased evapotranspiration. **[9, 10]**

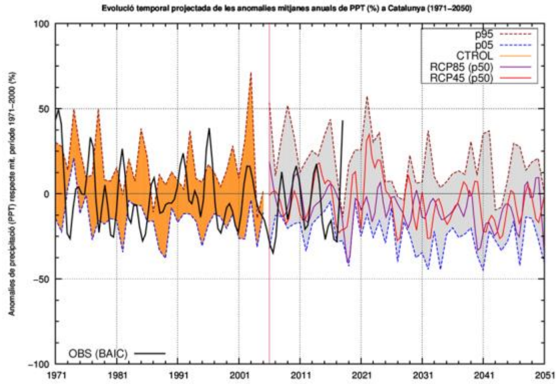

Figure 15. Projected precipitation changes in Catalonia under the RCP8.5 scenario. Note. The graph supports the discussion of future drought risk and seasonal precipitation decline. [10].

2.8.2 Meteocat scenario (RCP8.5)

The RCP8.5 scenario is based on the fact that present international goals are not achieved and therefore present a more pessimistic view. **[9]**

It states that this decrease will greatly affect Catalonia's summers and autumns, especially in the coastal and pre-coastal area (including Barcelona). **[7]** It is estimated that precipitation will decrease by 40% on a national scale, and by 75% in the summer months. It also projects that the most affected area of the region will be the north-east counties and Tarragonian coastlines, with a reduction of 15% in precipitation between the years 2021 and 2025. **[9]**

3. Practical work

3.1 Interviews

For this project we wanted to include an expert's point of view to guide us on how to approach the issue. We were lucky enough to be able to interview two professionals in the field: Mònica Usart, a Catalan meteorologist and specialist in water resource management, and other experts in the field.

We were also given the opportunity to do a one-week internship at Aigües de Barcelona to see the facilities and learn about how they work.

3.1.1 Mònica Usart (Catalan metereologist)

The interview with Mònica Usart gave us an expert view on Catalonia's complex and uncertain climate scenario, characterised by less and less precipitation and a rise in extreme events. Although current projections are considered reliable, she remarked on the need to prepare for more severe situations than those forecast.

Furthermore, she emphasised the importance of water management, especially desalination, taking into account the high energy expenses. She also explained that the solution does not simply depend on technology but on the political and structural decisions behind it. One of our main questions was about the government's mistakes and she said that the main one is simply the lack of continuity in projects once drought periods come to an end.

Finally, she concluded that adapting to future climate conditions is not a "one man job" and requires coordinated action between institutions. Only through sustained planning can we effectively address the water-related challenges of the future.

View appendices for full transcript of the interview.

3.1.2 Other experts (wish to remain anonymous)

This interview was conducted with other experts in the field who wish to remain anonymous. Nevertheless, the information they provided was very informative.

When asked about the future of Catalonia's climate, they mentioned both the increase in drought and the risk of flash flooding and other extreme precipitation events. They highlighted that whatever happens, it is almost guaranteed that Catalonia will have less usable water in the future. They also talked about the great amount of water being lost with the decline in snow in the Pyrenees (approximately 1,000 hm3) and the issues it is creating with it melting faster and earlier in the year, resulting in a complete absence of snow in the summer months.

They also agreed on the importance of water management, especially water reclamation and the existing Llobregat facility. When commenting on desalination infrastructure, they come to the same conclusion on its having a very high energy cost. Finally, they also talked about water efficiency in the metropolitan area and how Barcelona cannot be the only city held responsible since its consumption is already low.

In addition, they also reflected on one of the main issues of the current plan which is that it is reactive, and that water management has to look at things from a prevention point of view. Another point that we also found in our research was that the agricultural sector is very unprepared, making it more unstable and less productive. One last thing they added was that the government has treated drought "as a one-off problem" and has a tendency to communicate about drought when the reservoirs are already empty. They also place too much responsibility on citizens instead of seeing it as a structural problem.

View appendices for full transcript of the interview.

3.2 New proposed plan

After extensive research, we have been able to identify Catalonia's unique water situation, what the current measures are, and which new possibilities exist, especially on the renewable energy front. Following this, we have created a new drought plan, called the Catalan Sponge, inspired by China's flood engineering, since it strives to make Catalonia more drought resilient from the inside out.

After the 2021-2024 crisis, the Catalan government initiated a €2.3 billion investment targeting 70% non-reservoir water by 2027. This proposal takes some of their initiatives and proposes improvements as well as new ideas.

We have established a budget of €3,210 million over a period of 14 years, because the key to protecting Catalonia from future droughts is prevention.

3.2.1 Plan objectives

1. Water supply (new production)

a) Prioritise desalination over rainfall and snowmelt.

b) Produce water with renewable energy.

c) Make water reclamation the main source of water supply.

2. Agriculture

a) Cease flood irrigation in all farms.

b) Transition 100% to using drip irrigation by 2040.

c) Improve water access for farmers with the help of recycled water in drought years.

3.Urban life

a) Reduce water waste in homes.

b) Minimise average per capita water consumption with greywater recycling.

c) Prevent leakage and unnecessary water waste.

4. Government (legislative)

a) Redefine the thresholds for the "traffic light system".

b) Set new limits for water usage in drought periods.

c) Promote drought-friendly architecture (sponge infrastructure).

d) Include drought education in school curricula.

5. Financial

a) Apply for EU Green Deal and NextGenEU funding.

b) Finance new infrastructure through public-private partnerships.

c) Implement a progressive water tax on excessive use.

6. Diffusion campaign

a) Change how people think about reused water.

b) Publicise the traffic light system.

c) Share the proposal with water companies/initiatives.

3.3 Proposed measures

3.3.1 Water supply

By 2040, Catalonia cannot depend on the Pyrenees snowmelt or irregular rainfall. The goal of these measures is to transition gradually from a capture model (where precipitation is collected for use) to a production one, focused on desalination and water reclamation.

3.3.1.1 Expansion of the desalination network (ITAM)

The expansion of desalination plants is not a new idea. The Catalan Government and ACA have already formulated similar goals. By 2040, Catalonia's goal is to produce 280 hm^3/year through desalination (compared to the 80 hm^3 of 2024). **[44]**

These are the most important improvements that have been confirmed, although both plans have already been significantly stalled due to budget decisions. **[44]**

Tordera II (Blanes):

A planned expansion to 60 hm^3/year that should be in operation by 2026. This plant will ensure the water supply for the Girona coast and the northern metropolitan area. **[44]**

Foix Plant (Cubelles):

This plan includes the construction of a new plant with a capacity of 30 hm^3/year that should start by 2026 and be functional by 2029. This will relieve pressure on the Foix and Gaia reservoirs and provide water to the Penedès region. **[44]**

We aim to improve their plans by installing offshore wind farms near the coast of Blanes and Tarragona specifically to power these ITAMs instead of depending on electricity which costs around 0,85€/m^3. The fact is that commercial wind parks are just starting to be approved, so this measure can be expected to be possible between 2032 and 2035. **[45]** These plants would be owned by private companies, who in exchange would receive a long-term fixed-price contract with the government with the condition to prioritise energy supply to the water infrastructure before "the public grid".

3.3.1.2 Water reclamation of the river Besòs (ERA)

As discussed above, although desalination is a very effective way of producing new water, it is much more expensive. That is why the Catalan government and our plan strives for water reclamation to be a main source of water supply.

The government has already approved the construction of a water reclamation plant (ERA) in the Besòs basin, replicating the existing Llobregat one. **[46]** The wastewater from the northern Barcelona area will be treated and pumped upriver to the Mollet/Montcada area. This will create a river that never dries up, recharging the Besòs aquifers and providing a constant flow for the Sant Joan Despí treatment plant.

That said, the current plans are unclear on energy-sufficiency, a new standard that has been mandated by the EU Directive 2024/3019. **[47]** This regulation states, in brief, that all wastewater treatment plants above a 10.000 population equivalent, which is the case for the construction of the Besòs ERA, must achieve energy neutrality at a national level by December 31, 2040. The ACA has already committed to a €159m programme to increase renewable self-generation across Catalan water regeneration plants with an attempt to reduce co2 emissions. There are already many technologies that have been implemented such as biogas combustions, sewage sludge digestion, rooftop solar panels and heat recovery, with a target to cover 78% of energy consumption. **[48]**

Our plan proposes that since construction has not started yet on the ERA Besòs hub, it should be 100% energy neutral from the beginning, rather than relying on the network average to be in accordance with the Directive. This means that all of the energy consumed by the plant will be generated within the facility and therefore will reduce the ERA operating costs and is more sustainable long term.

Estimated costs (based on **[30]**):

Technology	**Energy cost (kWh/m³)**	**Financial cost (€/m³)**	**2040 target capacity**
Reservoir water	0,2-0,5	0,05-0,10	Only for peaks
Desalination (ITAM)	3,5-4,5	0,70-0,90	280 hm³/year
Reclamation (ERA)	0,5	0,10-0,25 (depends on transport)	160 hm³/year

3.3.2 Agriculture

In 2024, farmers faced up to 80% cuts in irrigation water as supply was diverted to cities for urban use. **[25, 26]** This caused a huge loss in crops and severe damage to the farming economy. The new plan will prohibit this because it uses thousands of unneeded litres of water and proposes new ways for irrigation for farmers for 2040. Another important point is that as of 2026, agriculture consumes about 70% of Catalonia's water, due to a practice called flood irrigation. **[12]**

The following proposals combat both of these issues with the final goal being to guarantee around 16% (approximately 112 hm³/year) of water needs for farmers so that even in a severe drought they can still survive without total crop loss.

3.3.2.1 Underground drip irrigation

Underground drip irrigation is a new form of technology that is only being tried in selected farms in Catalonia, most recently the Algerri-Balaguer irrigation community in June 2025. **[52]** The way it works is that sensors called IoTs measure soil moisture at different depths, and water is only released when the plants actually need it. **[53]** The expected water saving from this change in technology is a 40% reduction per hectare without losing crop yield. **[54]**

For the moment, underground drip irrigation has only been presented as a voluntary activity, but the proposed plan will offer incentives to promote its implementation. Ultimately, our goal is to prohibit flood irrigation in all farms in the Urgell and Ter-Llobregat basins by 2040.

The way this will work is that the earlier the farms implement this new technology, the more subsidies their installation will receive.

Timeline framework:

Year implemented	**Subsidy on installation costs**
2027-2029	70% government covered
2030-2032	50 % government covered
2033-2035	30% government covered
After 2035	No subsidy

3.3.2.2 Water reclamation for agricultural use

As of 2026, the Catalan government and the Urgell Canal irrigation community have already presented a proposal to modernise the Canals d'Urgell (farm pipelines), an agriculture project that is estimated to cost around €991 million. **[55]** However, at the end of 2025, many farmers were opposed to this idea due to the significant costs it would require on their part, so the project has been postponed until the second half of 2026. **[56]**

Taking advantage of this "pause in the initiative", we propose also integrating ERA water distribution into the already planned infrastructure renovations, rather than building a parallel network. This would generate a reliable water source, even in extreme droughts acting as a kind of minimum water guarantee for farms. Aside from that, this guarantee could incentivise farmers to accept the modernisation proposal.

Additionally, there is another positive effect of combining water reclamation and agricultural water consumption, since the recycled water is rich in nutrients like nitrogen and phosphorus, reducing the need for chemical fertilizers.

3.3.4 Urban life

3.3.4.1 Application of the Sponge City model

Like most cities in the world, Catalonia's cities (specifically the metropolitan area of Barcelona) are mostly built out of waterproof concrete blocks. As of right now, there is a lot of innovation in cities such as Shanghai that are creating new ways of engineering that protect the city from floods. The Sponge City model proposes that cities should absorb, clean and store water naturally. Currently, when it rains, water is lost into the sewers or causes flash floods, and as stated before, both rainless periods and erratic intense rainfall are projected for Catalonia's future climate. That is why we are proposing an adaptation of this model to make the most of the water when it does rain.

3.3.4.2 Permeable infrastructure and SUDS (sustainable urban drainage systems)

By 2040, the goal is to make 40% of all urban surfaces in Catalonia ''breathable'' or Sponge City friendly.

These are the architectural innovations we hope to include:

Porous pavements: All new sidewalks and public squares must be built with permeable concrete or terracotta bricks. This allows rainwater to filter directly into the soil rather than being lost in the drainage system.

Infiltration trenches: Underneath the main avenues (like Gran Via or Diagonal), we install ''infiltration trenches'', underground stone-filled channels that trap storm water and let it seep slowly into the aquifers.

Rain gardens: These are depressed green areas designed to capture runoff from the streets. In 2040, every neighbourhood park will work as a ''bio-retention cell'' that filters pollutants (oil from cars, dust) through specialized soil and plants before the water reaches the groundwater.

3.3.4.3 Technical standards for sponge construction

Some of these measures would also include modification of the building code to ensure drought-friendly architecture.

Blue-green roofs: All flat roofs on public buildings must be "Blue-green". This means a layer of vegetation (green) on top of a water storage tank (blue) that collects rainwater.

Basement cisterns: New skyscrapers and shopping centres must include a basement tank (minimum capacity of 5.000 litres per 100m² of roof) to store rainwater for irrigation.

3.3.4.4 Expansion of the 2040 greywater mandate

Greywater is one of the main causes of water waste in urban living since there is no real infrastructure to help people manage and reuse it. Barcelona City Council has recently approved its first Greywater Ordinance, which requires all new buildings with 16 or more dwellings to install greywater recycling systems, projected to save 136000 m3/ year across the city. **[50]** We want to expand on this idea by including all residential buildings, not just new ones and making it a law for all of Catalonia.

By 2040, every residential building with more than 8 dwellings in Catalonia must have an on-site treatment system. This mostly will be the water from showers and bathtubs that will only be reused for flushing toilets, cleaning stairs and water private balconies. Before that the water will be filtered through membrane bioreactors (MBR), disinfected with UV light, and sent back to a separate pipe system.

This measure is projected to reduce domestic potable water demand by 30-45% per household. **[51]**

Urban Feature	2024 Status (present)	2040 Status (Sponge)
Runoff coefficient	0.9 (90% water lost)	0.3 (only 30% lost)
Aquifer recharge	Very low (due to concrete)	High (due to SuDS)
Domestic reuse	< 2% of households	85% of households
Flood risk	High (sewer saturation)	Low (controlled absorption)

3.3.4.5 Creation of a water efficiency rating

We also want to create a new way of evaluating spaces by grading water efficiency similar to energy efficiency.

All buildings in Catalonia will receive a mandatory scoring that rates their water efficiency including: their greywater management, rainwater collection, and implementation of "sponge" architecture. From 2032, buildings must make this information public, and after 2035 buildings below a minimum score will not be allowed to be sold or rented out without making upgrades to their water efficiency infrastructure.

3.3.5 Government and legislative

The current special drought plan (PES) is reactive: it waits for the water to disappear. Our 2040 plan proposes a more proactive management model based on artificial intelligence (AI) and earlier intervention.

3.3.5.1 Redefining the thresholds

One of the many changes to the present drought plan is to increase the security margin to prevent an emergency state. In spite of this, we understand that this would need more complex and expert analysis to confirm the new thresholds.

These would be the new standards:

- **Pre-alert (green):** Would be triggered at 45%.
- Measure: Activation of all ERA plants at 100% capacity.
- **Alert (yellow):** Would be triggered at 35%
- Measure: Mandatory 10% pressure reduction in the urban network during nighttime (00:00 to 05:00) to minimize leaks.
- **Exceptionality (orange):** Would be triggered at 25%.
- Measure: Prohibition of filling and private swimming pools, regardless of the water source.
- **Emergency (red):** Would be triggered at 20%.
- Measure: Limit of 180 litres per person/day.

3.3.5.2 Improvement of the digital Catalan water network

As said before, the ACA is currently developing a digital twin pilot for water quality. **[33]** As of right now though, there are many different technologies that are working separately to look at different aspects of the Catalan water network. We want to improve it by combining the three new tools (smart detectors, creation of the digital twin and AI leak detection) to make it more effective, as well as the development of an app that acts like a personal water wallet.

- **Infrastructure expansion:**

The first step would be to expand smart detectors and acoustic sensors (AI) to the rest of Catalonia's pipeline. Then we would like to maximise the digital twin system to not only look at water quality but adapt it for operational network management. This was done in Valencia by the company Global Omnium and saved over 1 billion gallons of water a year. **[49]**

These three relatively new systems could totally revolutionise Catalonia's water network, since it would be able to monitor pipe pressure, identify leaks and have an overall better grasp on the entire system.

Personal water wallet:

The design of a new app that not only lets citizens view their water consumption, and what it is costing them per month. They would start off with a base quota of cheap water. If they exceed it, the price per litre triples automatically. This not only allows citizens to be conscious of their water usage but also ensures that the population stays within the 180-litre limit, especially in dire drought times.

3.3.5.3 Water literacy in schools

Another element in our plan is to promote drought and climate change consciousness in children at school.

That is why we want to make changes to the science curriculum at primary and secondary schools. This includes a class where kids learn about droughts, what the government is doing, visits to water infrastructure (desalination plants, etc), and how the children themselves can help with water conservation.

3.3.6 Financial sources

As stated before the 2021-2024 drought had devastating economic consequences across Catalonia. It estimated that the agricultural sector lost about €700 million, while industry and tourism also suffered significant disruptions. **[57]**

The total budget for the Catalan Sponge Plan is € 3,210 m, because it includes the € 2,300m already invested by the Catalan government. **[44]** The plan will not only protect land but all of Catalonia's population, as well as its economy and infrastructure from the risks of future droughts

These are the possible financial solutions we propose:

1.EU green deal and nextgen funds:

Since this plan fulfils the circular economy and climate adaptation goals of the European Union, Catalonia is eligible to apply for many non-refundable grants.

2.Public-Private partnerships:

As mentioned before for big projects, such as the offshore wind farms, we propose initiating public private partnerships. This means that the government would not have to pay for their construction, therefore it is not included in the budget, but would still have guaranteed access to it.

3.Water bill tax:

This would include a new surcharge that will only apply to citizens and companies who use a relatively "excessive" amount of water.

For households and families, it would only apply once one exceeds 100 litres/day. While companies would have to pay more (to be determined), because it ensures that they will have access to water even during a drought and they will not have to stop production.

3.3.7 Campaign diffusion

As the final part of our plan, we want to suggest a campaign that showcases how all of these measures are being implemented and motivates Catalonia's population to get involved in drought prevention.

We first want to create social media accounts for the proposal: L'Esponja Catalana (The Catalan Sponge), where users can find out about how they can help with at home measures but also receive updates on what the government is doing. This would help both with raising public awareness and building trust with Catalonia's citizens.

These are some of the ideas for posts:

- Fun facts about water.
- Photos of the improvements on installations.
- What the reservoir traffic light is at (monthly).
- Explanations on the proposed measures.

We also plan to contact schools and universities as another way of diffusing our campaign. Providing tours of the installations and creating competitions for which institution is the most water efficient in the neighbourhood,

Another aspect is how the tourism sector approaches water sustainability. We would love to be able to have a relationship with hotels in Catalonia to promote water saving for tourists and show light to their impact on the issue.

Finally, aside from sharing this project with the Water is Life Conference and our school, we hope to send it to the ACA and Aigües Barcelona to get their feedback and see if some of the measures could actually be implemented in the current government's drought plan.

3.3.8 Budget distribution

The total investment for the proposed 2040 plan The Catalan Sponge is at an estimated €910 million (estimated by AI). That being said, the Catalan government has already committed €2,300m for drought water infrastructure, including the Tordera II expansion, the ITAM Foix plant and the ERA Besòs hub. **[44]** Our budget just covers the new measures and improvements to the current ones making the total budget approximately € 3,210m.

This is not a single payment but a structured deployment of funds into five strategic areas:

A. Sustainable energy reforms (€130m):

- Offshore wind grid connection for ITAMs (**€87m)**
- Besòs ERA energy neutrality redesign (**€43m)**

B. Agriculture (€121m)

- Subsurface drip irrigation subsidy programme **(€54m)**

- ERA water integration into Urgell canal networks **(€67m)**

C. Urban retrofitting (sponge architecture) (€555m)

Sponge architecture:

- SUDS implementation **(€312m)**

- New construction regulations (blue-green roofs, etc.) **(€98m)**

Other measures:

- Greywater mandate **(€134m)**

- Water efficiency rating system **(€11m)**

D. Digital network and governance (€95m)

- Raised traffic light thresholds (no cost)

- Water network upgrades (detectors + digital twin expansion + AI leak detection) **(€78m)**

- Water Wallet app development and maintenance **(€17m)**

E. Education (€9m)

- Water literacy programme **(€9m)**

F. Campaign

- Social media **(no cost)**

- Tours and competitions (to be determined based on partnerships)

3.3.9 Timeline

To ensure financial stability and technical success, the Catalan Sponge plan is divided into three distinct phases. Each phase has specific milestones that must be met to trigger the next level of investment.

Phase 1: Digital and legislative changes (2026-2030)

- **2026:**

- - Launch of L'Esponja Catalana social media campaign.

- - Presentation of the plan at Water is Life Conference 2026 (Vught).

- - Creation of the Water Wallet app and digital infrastructure for smart metering.

- - Traffic light thresholds are taken under advisement for redefinition.

- - Offshore wind grid connection possibilities are analysed.

- **2027:**

- - First drip irrigation subsidies are available (70% government subsidy)

- - Drafting of a new water ordinance (this would create the legal basis for greywater mandate, sponge construction standard and water efficiency rating).

- - ERA water is beginning to be integrated into Urgell canal networks.

- - Initiation of the ERA Besòs redesign to be energy neutral.

- - Smart detectors and acoustic sensor pilots are deployed across Barcelona metropolitan water network.
- - The Water efficiency rating is developed and tested.

2028:

- Approval of the new water ordinance.

- Greywater mandate is active in all new 8+ dwelling buildings across Catalonia.

- New standards (blue-green roofs and basement cisterns) become mandatory for all new public buildings.

- The Water Wallet is launched for the Barcelona Metropolitan Area.

- AI leak detection software is integrated across the Barcelona Metropolitan Area network.

2029:

- ERA Besòs starts construction.

- ERA water system is integrated into the Urgell canals

- SUDS planning is approved and starts construction across Catalonia.

- The Water Wallet app expands to all of Catalonia.

- Smart detectors are expanded to all municipalities with 50,000+ inhabitants.

- Water literacy becomes a mandatory subject in the Catalan school curriculum.

2030:

- Drip irrigation subsidies drop to 50%.

- SUDS construction begins across all municipalities with 50,000+ inhabitants.

- Greywater mandate is extended to existing 8+ dwelling residential buildings.

- ERA water integration into Urgell canals is completed.

- AI leak detection is expanded to all municipalities with 50,000+ inhabitants.

Phase 2: Construction changes (2031-2035)

2031:

- - SUDS construction begins across all municipalities with 10,000+ inhabitants.
- - The new digital twin of the Catalan water network becomes operational.
- - Offshore wind integration desalination plants start construction.
- - Greywater systems are in 30% of eligible buildings.

2032:

- The water efficiency rating is made public (buildings must display the score)

- SUDS construction expands to all municipalities with 5,000+ inhabitants.

- AI leak detection is deployed across all Catalan municipalities.

-Greywater systems are in 55% of eligible buildings.

- **2033:**
- - Drip irrigation subsidies drop to 30%.
- - SUDS covers 20% of all urban surfaces in Catalonia.
- - Greywater systems are in 75% of eligible buildings.
- **2034:**
- - Offshore windfarms are connected to ITAMs.
- - SUDS covers 30% of all urban surfaces in Catalonia.
- - ERA Besòs is fully operational.
- - Greywater systems are in 90% of eligible buildings.

2035:

- - Buildings below a minimum water efficiency score cannot be sold or rented without upgrades.

- - SUDS covers 35% of all urban surfaces in Catalonia.

- ERA Besòs operates at 100% energy neutrality.

Phase 3: Final adaptations and changes (if necessary) (2036-2040)

2036:

- Greywater systems are active in 100% of eligible buildings across Catalonia.

- SUDS covers 40% of all urban surfaces in Catalonia.

- Water literacy is fully embedded across all Catalan schools.

2037:

-Review of The Catalan Sponge measures (adjustments if necessary)

2038:

-Flood irrigation is prohibited in all Urgell and Ter-Llobregat farms.

2039:

-Final technical corrections are completed.

2040:

- Catalonia achieves its target of 280 hm^3/year of non-natural water.

- The ERA Besòs is completely energy neutral.

- The full water network is operating under remodels.

This will allow the Catalan population to live much more independently from rainfall and achieve maximum water efficiency.

4. Results

Since the final product is purely hypothetical, we cannot really present any results of the effects the plan could have.

4.1 Final version of the drought plan: The Catalan Sponge

1. Produce 280 hm^3/year by 2040 through desalination plants that operate by offshore wind farms near the coast of Blanes and Tarragona.

2. Achieve 100% of neutral energy consumption for the planned Besòs ERA plant.

3. Mandate complete underground drip irrigation in farms in the Urgell and Ter-Llobregat basins by 2040 with incentives of subsidies for those who implement the technology earlier.

4. Integrate ERA water distribution in modernisation of the Canals d'Urgell to offer minimum guarantees for the farming industry.

5. Incorporate "sponge city infrastructure" so that by 2040 40% of all urban surfaces in Catalonia are using them. These architectural innovations include: porous pavements, infiltration trenches, rain gardens, blue-green roofs and basement cisterns.

6. Expand greywater mandate to all residential buildings in Catalonia with more than 8 dwellers.

7. Incorporate smart meters and AI leak detection across all of Catalonia, while combining it with the digital twin.

8. Create a water efficiency rating for all buildings in Catalonia that from 2032 must make it public. After 2035 buildings with a minimum score must complete renovations to their water efficiency before being leased or sold.

9. Redefine the drought thresholds for the traffic light system to be more proactive.

10. Improve the Catalan water network with the inclusion of smart meters and AI leak detection across Catalonia.

11. Develop a mobile application that acts as a "water wallet", where citizens can track their water consumption. When they exceed the base quota, the price per litre triples automatically.

12. Implement water literacy in primary and secondary education to promote water scarcity issues.

13. Apply for EU green deal and nextGen funds to support financial costs.

14. Initiate public-private partnerships to finance big construction developments.

15. Launch a water bill tax that applies to citizens and companies who exceed the amount of water they are entitled to.

Predicted results:

Indicator	2024 Status	2040 Target
Non-Natural water	100 hm^3	**440** hm^3(ITAM + ERA)
Agriculture Efficiency	45% (Flood)	**92% (Drip/Sensors)**
Urban Leakage	18% - 25%	**< 4%**
Independence from rain	15%	**82%**
Water cost to citizen	Variable/Expensive	**Stable (Renewable Energy)**

4. 2 Campaign diffusion

For this aspect of the plan, we were only able to go through the initial phases of the campaign, since we are waiting on approval from institutions like the ACA.

We simply created the instagram account for @lesponjacatalana and started promoting it within our school. Aside from this we are also waiting to submit our plan to Elisabeth Bergès (Communications department of Aigües de Barcelona).

Present social media following (10/05/2026):

Figure 16. Instagram profile of the L'Esponja Catalana dissemination campaign on 10 May 2026. Note. The screenshot documents the first stage of the campaign diffusion process. Source:

5. Conclusions and discussion

This research project set out to take a deeper look at how droughts affect Catalunya and what can be done to the already implemented measures to lessen the tolls on the environment, citizens and economy.

What initially seemed quite a dry research subject has really changed our perception of droughts and what we can do about them. It felt really empowering to create something that actually has real positive effects on a community that we ourselves take part in.

After looking back at our objectives, we can clearly see that our research goals have been reached and given us an ideal basis on which to work, that being Catalonia's past measures or one from other countries. We also managed to conduct very successful interviews and set up contacts for the future of our practical work (diffusion), as well as elaborating a new drought plan designed for 2040, integrating infrastructure, policy, and social strategies. We are fully aware that this project is only preliminary, and that approval of the plan would need much more data, interviews and auditing. It would also have been beneficial to see more of the relevant infrastructure across Catalonia.

As we have not been able to put our proposal to the test, we cannot really confirm our hypothesis. However, we are confident based on the presented predicted results that the proposed measures could reduce the effect of future droughts, especially in contrast to how the 2021-2024 crisis was managed. That said, we have been able to create real life changes with the diffusion of our campaign, by raising awareness of our proposal and the issues at hand.

We hope that we can continue this research and see some of our ideas brought to term. It would be very gratifying if these ideas would really have the effect we expect. Catalonia’s future remains very uncertain. The only thing that we can affirm is that it needs to be ready for every situation. This project is a first step to being more prepared.

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Finally, we would like to thank our families for the constant support and feedback.

Appendices:

Interview transcriptions (translated):

Mònica Usart:

1.Based on current climate trends, do you think the 15% rainfall reduction projected for 2040 is a realistic baseline, or should we prepare for an even drier scenario?

Yes, I consider this projection to be realistic, as it is based on climate models that are becoming increasingly accurate thanks to the growing availability of data and the ongoing development of climate change research. However, this 15% represents an average. This means that there will be years with much greater reductions, as we have already seen in recent droughts. Therefore, we must prepare for more extreme episodes. The Mediterranean is a region characterized by variability and extremes, so it is easy to shift from very dry years to more humid ones, even if the overall average indicates this reduction.

2.How does flash flooding impact drought infrastructure?

Infrastructure related to water management—such as reservoirs, dams, irrigation channels, treatment plants, and wells—can be negatively affected by very intense rainfall. When water falls suddenly, it is more difficult to make use of it: it can cause structural damage and does not efficiently contribute to replenishing reserves. For example, steady rainfall over several days is more useful for filling reservoirs than an extreme event. Furthermore, these types of rainfall hinder water infiltration into the soil, preventing proper aquifer recharge and leading to significant water loss.

3. How has the decrease in snow in the Pyrenees changed our water reserves, and what does this mean for 2040?

Although there are occasional years with abundant snowfall, like this one (2026) , the general trend shows a decrease in snowfall in the Pyrenees. This directly affects water reserves, as snow acts as a natural storage system that melts gradually over time. Without this reserve, water availability decreases, especially during dry years. Looking ahead to 2040, if this trend continues, natural reserves will decline, increasing vulnerability to drought conditions.

4. How can Catalonia aim to be 100% independent of rainfall by 2040?

This independence could be partially achieved through technologies such as desalination and water regeneration. The reuse of wastewater allows for the creation of a more circular system. However, these solutions involve high energy costs and may contribute to climate change if not managed properly. Moreover, total independence is neither realistic nor desirable, as rainfall is essential for natural ecosystems, including forests and biodiversity.

5. What is the biggest mistake the media or the government makes when communicating the severity of a drought to the general public?

There is often too much responsibility placed on the general public and citizens. Since the 2008 drought, citizens have developed a strong awareness and understanding of water-saving practices. The issue is not a lack of information, but rather a lack of structural action. Therefore, communication should focus more on political responsibility and the need to implement projects and infrastructure, rather than repeatedly advising the population.

6. If you were designing an emergency plan for 2040, would you change the current "traffic light" triggers (Alert, Exceptionality, Emergency) to make them more proactive?

I would not modify it without thorough analysis. This system is well-structured and adapted to different regions. Furthermore, people tend to respond more to specific restrictions than to alert levels themselves. Therefore, I consider the current system to be appropriate.

7. In a future where "New Water" (reclaimed and desalinated) is the main source, how can we convince society to trust and value this "technological" water as much as rain?

Education is key. It is important to explain the processes involved in producing this type of water, as well as the associated energy and economic costs. If the public understands the complexity behind obtaining this water, it will be easier for them to value it as much as rainwater.

8. Which economic sector in Catalonia do you think is currently the least prepared for the climate reality of 2040?

The tourism sector will be one of the most affected. Water restrictions and rising temperatures may reduce the attractiveness of certain areas, especially during the summer, when conditions may become difficult to endure.

9. What do you think has been the biggest mistake in past droughts in Catalonia that has been repeated throughout your experience as a meteorologist?

The main mistake has been the lack of continuity in projects once a drought ends. During crisis periods, many initiatives and investments are generated, but once conditions improve, they are often abandoned. This prevents effective preparation for future droughts, as many projects require time, political stability, and resources to be properly developed.

10. What do you consider to be the most important infrastructure or technology that Catalonia must finish before 2040?

I would prioritize water regeneration technologies, as they allow for the production of water resources with lower energy costs compared to desalination. These types of infrastructures are essential to ensure a sustainable water supply in the future

Other experts:

1. Based on current climate trends, do you think the projected 15% reduction in rainfall by 2040 is a realistic benchmark, or should we prepare for an even drier scenario?

The 2025 Report on Climate Change Risk and Impact Assessment in Spain (ERICC, 2025) describes models indicating an average annual reduction of 4% to 16% by the end of the century, though with marked regional variation. An increase in seasonal irregularity is expected, with wetter winters in the north and drier autumns and summers in the south and east.

The evidence suggests that the main problem will not be so much an overall reduction in average rainfall, where there is no clear trend in terms of change in mean precipitation, but rather a worse distribution of rainfall. Extreme precipitation events (above the 95th percentile) could increase in intensity, raising the risk of flash floods and erosion.

In short, as water managers, we will have less water that can actually be used.

2. How do flash floods affect drought related infrastructure?

Climate change is generating a pattern of long dry periods interrupted by increasingly violent torrential episodes, subjecting water infrastructure to stresses it was never designed to handle.

The damage is multifaceted: floods disable pumping stations and water treatment plants; the sediment they carry silts up reservoirs, reducing their capacity precisely when it is most needed; and distribution networks are left damaged or contaminated. On top of this, many vulnerable infrastructures (including water management ones) remain located in high flood risk areas. Furthermore, combined events (such as coastal storms coinciding with floods) have already caused recurring problems, such as those experienced at the Llevant collector.

3. How has the decline in snow in the Pyrenees changed our water reserves, and what does this mean for the future?

Over the past 40 years, the average temperature in the Pyrenean mountain basins has risen by more than 0.5°C, snowfall has decreased by around 100 mm, and this translates into a loss of approximately 1,000 hm^3 per year in available water resources.

The consequences are already visible: peak flows typical of snowmelt have been occurring earlier in the season, which desynchronizes water availability from actual demand. The water arrives sooner and in smaller quantities, and in summer, when it is needed most, there is no longer any snowpack left to feed the rivers.

Looking ahead, the outlook is worrying. Each degree of temperature increase over the 21st century will represent a 20% decline in snow accumulation and a reduction of 20 to 30 days in the duration of the snowpack. Models even point to a 50 to 60% decrease in the water content of the snowpack under the most pessimistic scenarios.

All of this puts at risk the water resources that depend on snowmelt in mountain areas, directly affecting urban supply, agriculture, and hydroelectric generation across the entire northeastern peninsula, including Catalonia.

4. How can Catalonia aspire to be 100% independent from rainfall in the future?

In the Government Agreement of 27 August 2024, the Generalitat set a target for 70% of the water supplied by 2027 to be independent of rainfall. Achieving this figure requires combining different tools: first, the promotion of reclaimed water, which has proven to be an effective lever for ensuring water resilience, both locally and internationally.

During the 2022 to 2025 drought, indirect potable reuse on the Llobregat was decisive, preventing the emptying of reservoirs during the most critical months. This solution involves recycling water and pumping it upstream into the river to be captured and treated again. Its great advantage is that it does not depend on the climate: as long as there is water to treat, there is water to reuse, and it has low energy costs and environmental impact. To meet the Generalitat's target, replicating this reuse scheme on the Besòs is essential.

The second approach is desalination and the use of water resources that have not yet been exploited. Despite its high energy cost, converting saltwater into drinking water allows supply to be guaranteed regardless of rainfall or reservoir levels. Recovering aquifers and making greater use of rivers are measures that allow more to be done with the water that already exists, without needing to generate new sources.

The third is efficiency in consumption and in transport and distribution networks. In the metropolitan area, consumption is already very low (close to 100 L per person per day, and even lower during drought periods), leaving little room for maneuver. Similarly, network efficiency is very high (85.26% in 2024), so while these measures may be more effective in other territories, in the Barcelona metropolitan area they cannot be a solution on their own.

Together, these three strategies make it possible to break the historical dependence on rainfall by diversifying water sources and closing the water cycle rather than leaving it at the mercy of the climate.

5. What is the biggest mistake made by the media and the government when communicating the severity of a drought to the public?

One common mistake is treating drought as a one off problem rather than a structural one. There is a tendency to communicate about drought only when reservoirs are empty, and to consider the problem solved once they fill up again. The amount of water stored in reservoirs is just a snapshot, not a guarantee for the future. When the perception of risk decreases, there is a risk that the adaptation measures needed to prevent future droughts get deprioritized. Our territory has a structural water deficit that goes beyond the meteorological situation, and climate change will put this deficit under even greater strain.

Another common mistake is placing too much emphasis on public awareness, encouraging consumption reductions, which as explained above are already very low, as well as measures aimed at making the drought visible to citizens. One example was halting irrigation in parks and gardens, even in cases where alternative water sources were being used, with fatal consequences for urban vegetation.

6. In the climate emergency prevention plan, would you change the current "traffic light" alert levels (alert, exceptionality, emergency) to make them more proactive?

More than the traffic light system itself, what needs rethinking in the Special Drought Plan (PES) are the consumption reduction ratios associated with each stage. In our view, the existing system places too much emphasis on consumption reductions rather than on the actual impact associated with water use. The PES should give greater consideration to the origin of the water and its associated impact, encouraging large users to switch to alternative water resources. This can be achieved through the use of indicators such as the water footprint. Similarly, the PES sets flat rate reduction benchmarks by type of use (industrial, agricultural, etc.). The starting point should be taken into account, considering the existence of prior efficiency measures.

In a context of structural drought such as that projected by science, we need a system that anticipates action and promotes solutions such as the use of reclaimed water long before we find ourselves back in an alert situation.

7. Which economic sector in Catalonia do you think is least prepared for the climate reality of the future?

One of the economic sectors in Catalonia likely to suffer the greatest impact is the agricultural sector. Farming and livestock depend directly on factors such as water, temperature, and rainfall, making them especially vulnerable to climate change. In a context of rising temperatures and more frequent droughts such as those already being observed on the peninsula, water availability decreases and crops, especially rainfed ones, become more unstable and less productive. Furthermore, this sector consumes a large share of available water resources, which worsens its situation in scarcity scenarios.

However, success stories such as that of the Murcia Region, where 98% of treated water is reused mainly for agricultural purposes, show that adaptation in this sector is possible.

8. What do you consider to have been the biggest mistake made during past droughts in Catalonia? And do you think we have learned from it or changed our approach?

One of the biggest mistakes in past droughts was managing water reactively rather than preventively. That is, measures were taken once the drought was already severe, through consumption restrictions or emergency measures, rather than anticipating it with long term structural planning. This lack of foresight resulted in a heavy dependence on rainfall and reservoirs, without sufficiently diversifying water sources.

As for whether lessons have been learned, the infrastructure developed during the 2008 drought (the ITAM Prat and the ERA Baix Llobregat) proved key to overcoming the most recent drought. This has led to the adaptation measures approved during the last drought continuing to be implemented. In this sense, steps forward have been taken, but it is essential to guarantee the completion of these works as a safeguard for future climate scenarios.

9. What infrastructure or technology do you consider most important for Catalonia to develop in order to prevent the effects of climate change before 2040?

In our field, reuse at the Besòs hub, replicating the pre potable reuse model from the Llobregat, combined with a new drinking water treatment plant drawing from surface water on the Besòs, are key. In parallel, deploying direct supply of reclaimed water to large consumers is also essential.

Rather than relying solely on new sources such as desalination, the great challenge is to make far better use of the water already available. Reuse stands out because it is more sustainable in the long term, has a lower energy impact, and allows existing resources to be optimized. Together, making a decisive commitment to this technology could be one of the most strategic changes for guaranteeing water supply in Catalonia in the coming decades. This would reduce pressure on reservoirs and aquifers and decrease dependence on external sources, in line with the objectives of the Taula del Ter.

Political participation in regional water management

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Abstract

This paper examines the development of water governance and management policy in the 's-Hertogenbosch region since the flooding of the A2 highway in 1995. The research analyses how regional and, where relevant, national water policies have evolved in response to recurring flood risks and increasing climate change related influences.

Attention is paid to the role of political parties in shaping water policy. The main research question is: how has the water policy in the 's-Hertogenbosch region developed in the last 35 years?

The hypothesis is that the 1995 flooding acted as a turning point, leading to a shift towards more foreseen and climate-adaptive water management policies over time. It is expected that the results will show a focus on climate-adaptive water management, because of the growing concern of climate change and flood risks. This paper is based on the analysis of policy documents, governmental reports, party programs, and includes opinions from local residents and relevant information from credible online sources. All these things help illustrate how water governance has changed over time in the 's-Hertogenbosch region and how political participation in water management works.

Keywords

Flood risk**,** water governance, policy development, 's-Hertogenbosch region

1 Introduction

The Netherlands is characterized by a flat, low-lying landscape, a long coastline, and several major rivers such as the Rhine and Meuse. Nearly one third of the Netherlands is below sea level. This geographical setting has resulted in a history of water problems.

The Netherlands is known for its water management system, including dikes, dams and dunes. Nevertheless, low-lying cities remain an at-risk area of flooding. The geographical location of 's-Hertogenbosch is an important factor to consider, when looking back at the history of flooding in the 's-Hertogenbosch region [1].

On the 30th of January in 1995, the dikes of the river Dommel broke, resulting in water being released with enormous force. In the days prior to the event it was pouring down rain; as a result, river levels increased expeditiously. This situation was further expanded by meltwater from the Ardennes and the North of France, which flowed into the Meuse [2, 3].

As a precaution hundreds of thousands of people were evacuated [4]. It was the largest evacuation in the Netherlands, after World War II. The evacuations started on the 30th of January, with 75,000 people who were advised to leave their homes. At half past eight in the evening, the dike of the Dommel breached, causing the Nature reserve the Bossche Broek to flood. In addition, soon after, the A2 motorway flooded as well, as is shown in figures 1, 2 and 3.

In the days that followed, over 250,000 people were evacuated. Not only were thousands of people evacuated, but also over a million animals were saved as well. The overall damage was not disastrous; nonetheless, this 'almost disaster' did leave an enormous mark in Dutch history [4]. The total damages amounted to approximately 183 million euros. This money was spent on things such as increased deployment of police, military, damages for evacuees and companies [5]. No prior research exists on whether individuals have become victims of emotional damage due to floods.

This disaster exposed the vulnerability, of Dutch citizens, when a flooding occurs. In the decades that followed, more recognition of climate change and flood risks has led to developments in water governance. However, this raises the question to what extent the flooding of 1995 truly acted as a turning point for regional and national water management [2, 6-8].

After the flooding of 1995 regional and district water authorities were forced to take measures to prevent similar disasters. Political parties at both the regional and national levels played a vital role in shaping the current state of water governance [9-10].

In the following figures the flooding of 1995 is shown.

Figure 1: Surfer on the highway [13]

Figure 2: Rescue operation [14]

Figure 3: Highway shown underwater [15]

2.1 The Purpose of the Research

Due to climate change, flood risk is intensifying, placing increasing pressure on rivers and sewer systems that are not always capable of handling this volume of water [16].

This research examines how decision-making processes within water authorities and political parties are influenced by flood events, risks and hydrological data; moreover, how this information is transformed into policy [17,18].

Low-lying cities, especially those located near rivers, are vulnerable to flooding. These areas often lie below the Normaal Amsterdams Peil (NAP), increasing their exposure to flood risks [18]. This is further demonstrated in Figures 4 and 5.

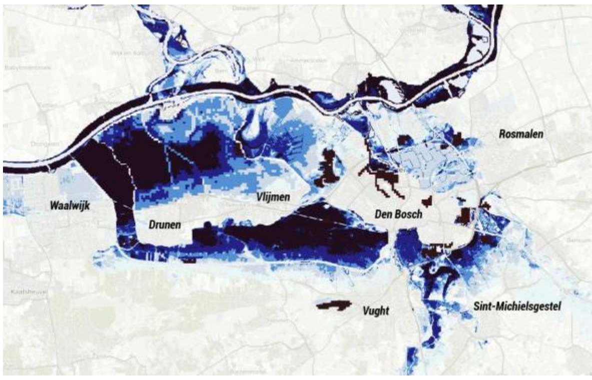

Figure 4: Areas with a moderate risk of flooding near 's-Hertogenbosch [19]

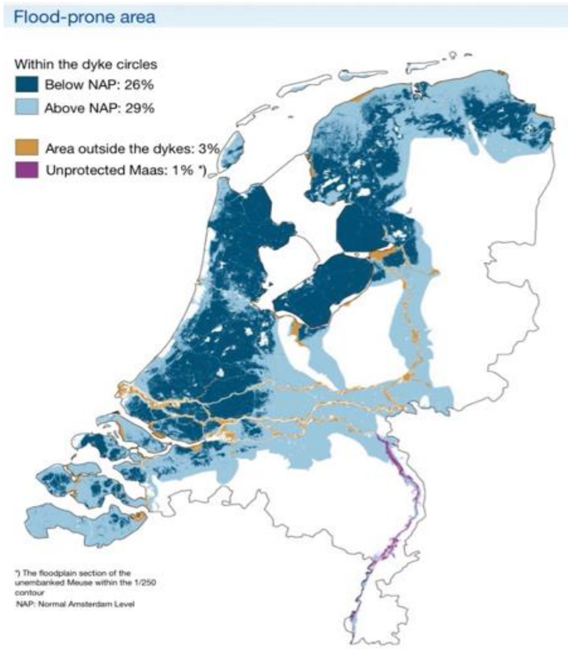

Figure 5: Flood prone areas [17]

2.2 Method of Research

The research was divided into four main parts. In the first part, the most important aspect was to understand the topic by participating in a work-shadowing day at the Aa en Maas water board. This provided practical insight into how water authority operates. This included understanding its advisory role in water management.

The second part consisted of conducting online research, including reviewing local and national party programs. These documents were used to examine how much has changed since the flooding of 1995. The data was analyzed and categorized into three time periods: 1994-2002, 2002-2010 and 2010-2026.

Thirdly, local residents participated in a questionnaire about the flooding of 1995. The survey consists of 21 questions, and a total of 71 respondents complete the questionnaire. This provides insight on the emotional damage of this 'almost disaster'. The survey not only examines emotional responses to the 1995 flooding, but also assesses respondents' trust in government, awareness of political decision-making, and perceptions of current water management policies.

Lastly, the collected data from political documents, survey responses, water authorities, and online sources are compared and analyzed in order to detect patterns and developments in water governance over the past 35 years.

3 Results of the Research

3.1 Dutch political context

The Netherlands is a parliamentary democracy. This means citizens elect a group of representatives. This group is called the Parliament, and it consists of two chambers: the Senate and the House of Representatives. The House of Representatives plays a key role in proposing and amending legislation, while the Senate reviews the proposed laws and checks if they are workable and legally correct. In practice, the government is almost always formed through coalitions between several political parties [20].

The diagram, figure 6, shows how political parties in the Netherlands are positioned. Left-wing parties generally emphasize social equality, government intervention and environmental protection. Right-wing parties often focus more on economic freedom, market solutions and individual responsibility. Progressive parties advocate for social change and climate policies, whereas conservative parties prioritize stability, tradition and gradual change.

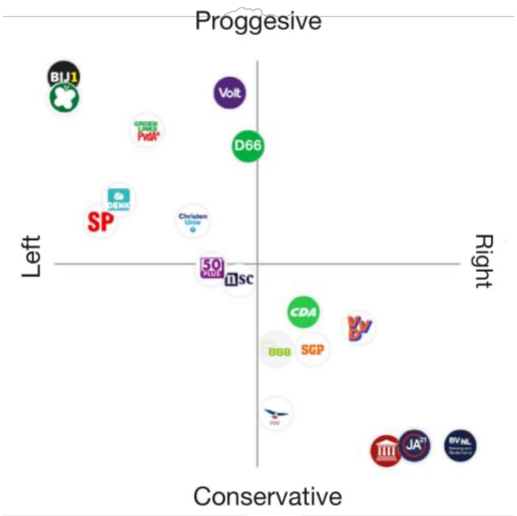

Figure 6: Political Spectrum [21]

3.2 The Start of Political Attention Regarding Water Risk (1994-2002)

In the period 1994-2002, the Kok government was in power. This was the first case of a purple government.

A purple government is a coalition between social-democrats, liberals, and without Christian-democrats (CDA, Christian Democratic Appeal) [22, 25].

The cabinet that formed consisted out of PvdA (Labour Party), VVD (People's Party for Freedom and Democracy) and D66 (Democrats 66). These parties still remain very prominent in 2026 [23-24].

Analysis of party programs from 1994-1998 and 1998-2002 shows that flood risk and water governance received limited political attention during this period. Most parties focused on broader environmental issues such as water purification and ground subsidence. References to flooding are largely absent across the main political parties, including PvdA, VVD, D66, GroenLinks (GreenLeft) and CDA [26-30].

When looking at these party programs, it is important to realize that these plans were made before the flooding of 1995. Nevertheless, on the 13th of January in 1995, the government did come up with the Deltaplan Grote Rivieren, in response of the extremely high water levels in the Rhine and Meuse. The Deltaplan Grote Rivieren will be further elaborated on in a later section [31].

Local parties, including the CDA, PvdA, VVD, D66 and GroenLinks arranged crisis support after the floods. The main contributions were flood defenses, evacuation preparations and forming cooperations with water authorities.

The 1998 party programs indicate that water governance had not yet become a central priority. While most parties still do not explicitly refer to water or the 1995 flooding event, D66 is the only party that briefly acknowledges flood safety and a plan to improve the dikes before 2001 [32-36].

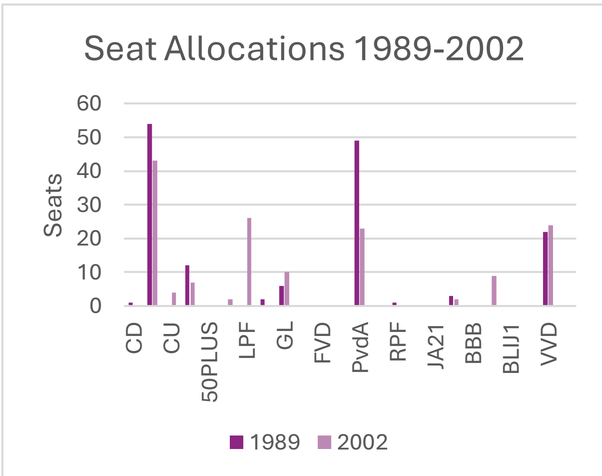

Figure 7: Seat Allocations 1989-2002 [22-24, 37-38]

3.3 Introduction of "Room for Water" (2002-2010)

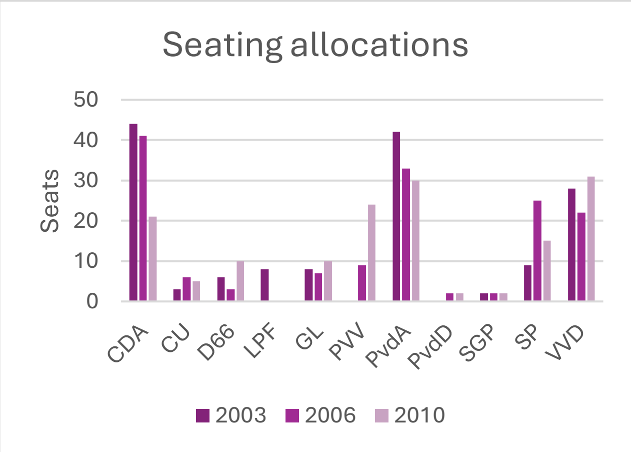

Figure 8: Seat allocations [37-40]

In 2002, a center- right government ruled in the Netherlands [37]. This period marks a structural integration of flood risk management into spatial planning and water governance.

Analysis of party programs from 2002 onward shows that flood risk and water management received increasing political attention compared to the previous period [41-45]. A key development is the emergence of the "Room for the Rivers" (Ruimte voor de rivieren).

During this period, there is a political support for the "Room for Water" approach from multiple major parties. Flood risk management is linked more to spatial planning and climate adaptation. However, despite the agreement, differences remain in emphasis. Some parties prioritize integrated spatial planning and environmental policy, whereas others focus more on combining water management with infrastructure and economic development [41-45].

After the fall of the cabinet in 2002, the electoral programs did not demonstrate a fundamental shift in water policy. Moreover, some additions were made to specify the plans. Mostly, the principle of "making space for water" became increasingly important [41-45].

In the period 2006-2010, the plan of "making space for water" is further developed and becomes more firmly mentioned in political programs. Water management is increasingly linked to spatial planning and broader environmental challenges, particularly climate change [46]. Most parties support the continuation of the "Room for the Rivers" approach. Furthermore, flood risk management is incorporated more into policy during this time [46-49].

Room for Water is a more umbrella term, of which room for rivers a part of is. Room for Rivers is a program specifically focused on river systems. In addition, the concept of making space for water is often used as a general policy principle, rather than a formal program. While these terms are closely related, Room for Rivers is the most concrete and implemented policy. The idea of giving rivers more space emerged after the high-water levels of 1993 and 1995. However, the Room for Rivers program was formally implemented in 2006.
The main goal was to be prepared for floods and droughts. As it says in the name the plan is to give rivers more room, instead of just improving the dikes [50].

The Delta Program is a national long-term strategy aimed at ensuring water safety in the Netherlands. It builds on past plans like Room for Rivers by ensuring that the country remains protected. For regions such as 's-Hertogenbosch, this program translates into continuous investments in flood defense, sustainable water management and spatial adaptation [51].

3.4 Climate change and water governance (2010-2026)

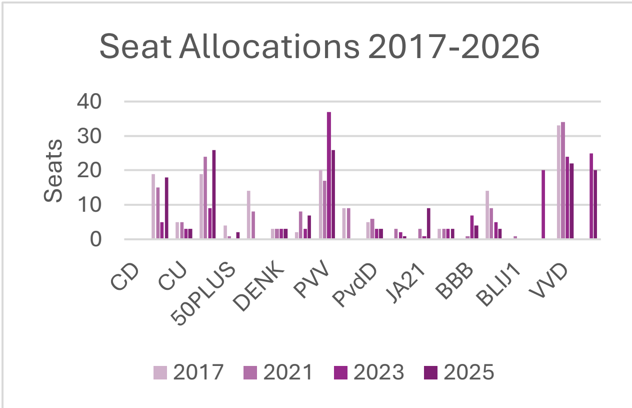

Figure 9: Seat Allocations [53-55]

In the period of 2010-2017, water governance got more attention. Flood risk is no longer treated solely as a technical issue, but is linked more to climate change.

The Room for the Rivers plan is still the dominant framework during these election party programs. However, the differences between political parties are more visible. While some parties emphasize on strengthening dikes and improving water infrastructure, others promote flood protection though nature restoration and spatial planning [55-58]. At the same time, water governance is not prioritized across all parties. This indicates that water governance is not yet a central focus in all political agendas [59].

In the period 2017-2021, water management and climate adaptation are mentioned more frequently, especially in the context of climate change, compared to the previous period. The policy direction remains stable; however, there are no major shifts.

The principles of Room for the River remain indirectly present in policies, although they are not always highlighted in party programs [60-63]. Differences between political parties still persist, as was explained in one of the previous paragraphs. This period is characterized by continuity rather than change [59,60].

In the period of 2021-2023, climate change becomes a more significant issue in political discourse, in addition influencing discussions on water management. Some parties emphasize the urgency of climate change and the need for a change, while different parties adopt a pragmatic or cautious approach. At the same time, there are parties that question the relevance of climate change related risks. Because of these varied views political polarization around climate change and water governance emerges [64-67].

In the period of 2023-2026, climate policy is mentioned in every party program. Despite the acknowledgment of climate policy, there is still a lot of diversity of opinions. These different views exist between long-term climate risks and the extent to which existing water management systems should be adapted [68-71].

Existing project structures, including the “Room for the Rivers” approach and the Delta Program, continue to play a role. Although they are increasingly discussed in terms of whether they should update the plan to address future climate change risks [70-71].

Over time, a clearer correlation can be observed between political parties and water governance approaches. Parties such as GroenLinks-PvdA increasingly emphasize on climate adaptation, nature-based solutions and spatial planning. In contrast to parties such as VVD and CDA who tend to focus more on balancing water safety with economic development and infrastructure. More critical positions regarding climate-related water policy can be found in parties such as the PVV, which places less emphasis on climate change as a driving factor. This indicates that water governance has become more politically differentiated.

3.5 Survey

A randomly selected group of inhabitants of the ’s-Hertogenbosch region filled out the survey on water governance. The questions are divided into four sections. The first section is related to general questions about; age and how long they have lived in the ’s-Hertogenbosch region. The second section contains questions about the flooding of 1995 and the role the government played during that event.
The third part includes questions about the current situation, and the upcoming struggles climate change brings. The final part concerns politics and the future situation.

Not everyone was old enough to remember the flooding event, as can be seen in Figure 10.

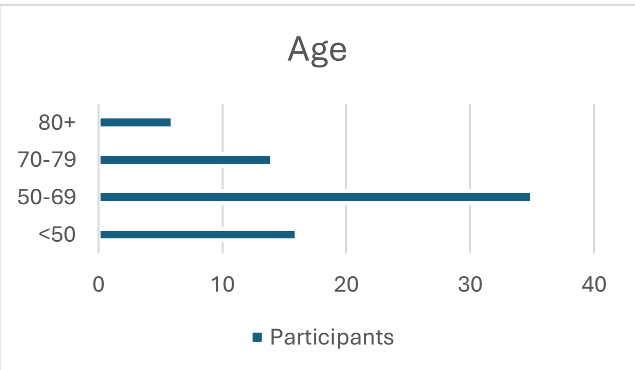

Figure 10: Age Registration

In the second part one of the first questions was, “how much do you remember of the flooding in 1995?” Additionally, it can be deduced from the given answers that this event is well known in this region and often remembered.

What is remembered most about the flooding is the media coverage of it. Furthermore, 22% mentioned the disruption of their daily lives and the threat of evacuations.
After these answers, the question was raised about the faith the people had in the government during this “almost disaster”. Thirty percent of the respondents reported that they were doubtful of the government, as well as thirteen percent mentioning they had no faith at all during this disaster.

In the third part of the survey, climate change was addressed. Only 29% of the respondents indicated that they were not scared of climate change. The vast majority expressed their concern regarding climate change. This group alluded to the need for better communication, clearer plans and additional education on this matter.

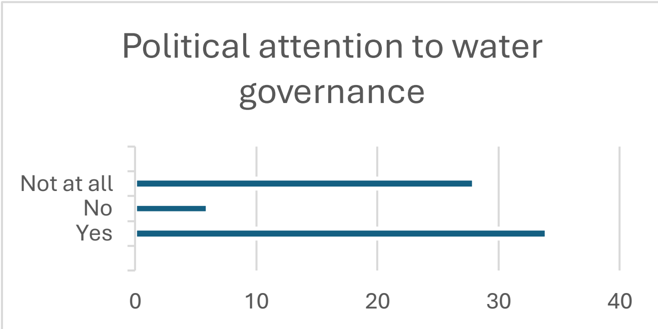

Figure 11: Water Safety Amongst Participants

In Figure 11, the question was asked about how much water management is represented in politics and whether it needs more attention. The answers are varied, and it is interesting to see how almost half of all participants expressed their concern over too little attention.

4. Conclusion

This paper examined how water governance in the ’s-Hertogenbosch region has developed over the past 35 years, with extra attention to the impact of the flooding event of 1995. Based on the analysis of party programs, policy developments and survey results, it can be concluded that the flooding of 1995 truly was a turning point in water governance.

Before 1995, water governance and flood risks received little to no political attention. Political parties mainly focused on general environmental issues. The flooding of 1995 exposed the vulnerable state of the Netherlands regarding water.

Water governance gradually became more integrated into political agendas. This was made clear in the Room for Rivers approach, which focused on a more adaptive solutions, as opposed to defensive ones.

From 2010 onwards, climate change became a greater concern in water governance. Flood risk was no longer an isolated issue; it turned into a broader climate issue. There is still a struggle with political diversity on this topic, and specifically regarding how water management should be implemented.

The survey results support these findings. Most respondents were aware of the 1995 flooding and recognized changes in water management since then. However, at the same time, trust in the government during this event was on the low side.

In conclusion, the hypothesis is confirmed: the 1995 flooding acted as a turning point for long-term changes in water governance. Potential improvements for similar research would be; to define the types of questions the survey needs to address the main question. Furthermore, instead of looking at the national political party programs, a deeper examination of regional programs and changes would better answer the question. Moreover, the sources were scattered when I wrote the paper, and it took far too long to sort this out.

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Assessing Governance Model in Mangrove Management: A Case Study of State-Owned Enterprise (SOE) – Community Collaboration in Tanjung Pasir, Indonesia

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Abstract

Mangroves play crucial roles for water protection, including filtering pollutants, reducing flood-risk, and supporting economic sustainability for local communities. Various parties have taken the initiative, and many research studies have been done, both aiming to preserve mangroves. However, less attention was directed to understanding the governance of these efforts, particularly about mangrove management in Tangerang.

This research focuses on investigating mangrove management in Tanjung Pasir, a local mangrove area in Tangerang. The research aims to find out how the mangroves are governed and how the current management supports the long-term sustainability in Indonesia. Data from this research are obtained through survey, in-depth interviews, field observations, and focus-group discussions with the local and non-local people involved in mangrove management. The finding shows that Tanjung Pasir mangrove is governed through a hybrid model between CBM and MSP. Strong community participation is encouraged by benefits, while external stakeholders provide additional support by planting and maintenance activities. Overall, this model can support the long-term sustainability of the mangrove ecosystem and provide an ideal local solution for the ecological and economic sustainability of communities living in the Tangerang coastal area.

Keywords

mangrove, mangrove management, conservation, natural resources

1 Purpose of the Investigation

Mangroves are a local solution to both ecological and economic problems in Indonesia. They play an important role in protecting coastal areas and the surrounding infrastructure from ecological problems like abrasion and flooding. Aside from that, mangroves contribute to carbon sequestration and storage, provide habitats for many species, support fisheries and offer cultural ecosystem services like ecotourism and education. Economic benefits are also found as mangroves are cost-effective forms of ecosystem management that contributes to biodiversity conservation, climate change mitigation, and sustainable development [1].

However, mangrove areas in Indonesia continue to decline. The Ministry of Marine Affairs and Fisheries state that the rate of abrasion in Indonesia reaches 1,950 ha per year, with an average coastline loss of 420 km per year, where most coastal damage is caused by the loss of mangrove forests as natural coastal protectors [2]. Mangrove deforestation in Indonesia between 2009-2019 reached 182,091 ha, one of the main drivers being infrastructure development [3].

In addition, according to previous research done by Utami, et. al, 2018, there is also a challenge in managing mangrove ecosystems due to overlapping governance and regulations, often involving multiple ministries and institutions, this creates complexities that are not well synchronized with one another [4].

Despite these challenges, the mangrove forests in Tanjung Pasir, have managed to survive and sustain their ecological functions until now. Therefore, this study aims to understand and assess the governance model in managing the mangrove ecosystem in Tanjung Pasir and how the management has enabled it to continue surviving and sustaining.

2 Method of the investigation

This research employed a mix-method case study approach to examine mangrove governance in Tanjung Pasir. The study integrated surveys, interviews, focus group discussion (FGD), and field observations to investigate governance practices, stakeholders participation, and perception towards mangrove sustainability.

A non-probability sampling technique, named purposive sampling, was employed for both quantitative and qualitative data. Respondents were intentionally selected from stakeholder groups relevant to the mangrove ecosystem, including local residents, mangrove workers, regular visitors, and non-governmental organisations (NGO). Participants were approached directly in the mangrove area based on their availability and willingness to participate during the field survey.

The data were analysed based on six governance aspects. Quantitative data obtained from likert scale surveys were analysed descriptively by calculating and interpreting respondents' score to evaluate mangrove governance practice. Qualitative data from interviews, FGDs, and field observations were analysed descriptively to support, explain, and validate the survey findings.

3 Results of the experiment

Table 1: Professional Background of Survey Respondents

Profession	Number
Perhutani (State-Owned Enterprise)	1
Non-Governmental Organization	2
Local Residents	7
Mangrove Worker	7
Regular visitors	3

Table 2: Profile of Interview and FGD Participants

Code	Stakeholder Type
HJ	Mangrove Worker - Security
BW	Local Resident
DL	Neighboring Village Resident
PH	Government Official Representative
PB	Non-Governmental Organization Representative
BR	Education Institution Representative

There are twenty respondents and six interviewees/FGD participants. Table 1 shows the occupational backgrounds of respondents surveyed in the mangrove forest area of Tanjung Pasir. Table 2 provides the stakeholder profile information of the respondents who participated in the interviews.

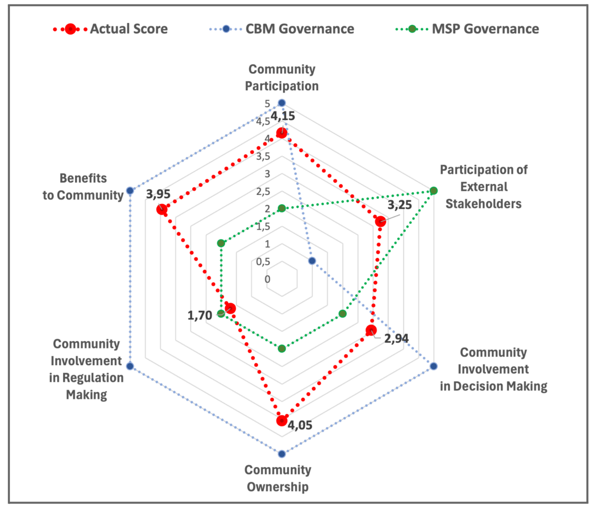

Figure 1. Governance Aspect in Tanjung Pasir Mangrove, Indonesia

Tanjung Pasir mangrove ecosystem management, as shown by Figure 1, is an example of a hybrid governance system between Community-Based Management (CBM) and Multi-Stakeholder Participation (MSP). The actual scores (red line) are positioned between the ideal CBM and MSP pattern, which is shown by blue and green lines respectively. In CBM governance, local communities play dominant roles in initiating, managing, and making decisions regarding the natural resources in mangrove. In contrast, MSP governance involves collaboration of multi stakeholders such as local communities, government institutions, NGO, academic institutions, and other external parties in the management process.

Community participation, community ownership, and benefits to the community scores are relatively high, and closer to the CBM pattern of governance, indicating that local people are actively involved and play crucial roles in mangroves management. However, the relatively high participation of external stakeholders also reflects characteristics of MSP governance. Therefore the governance of Tanjung Pasir Mangrove cannot be categorised as purely CBM or MSP, but rather as a combination of both governance.

The local communities take active part in activities for conservation of the environment like planting mangroves, maintaining the environment, and others in the mangrove ecosystem. The finding is supported by interview data. PH, one of the interview participants, stated that the community actively engages itself in maintaining and protecting the mangrove area:

"Kalau untuk masyarakat alhamdulillah, kita bantu juga dalam bentuk melaksanakan pemeliharaan atau menjaga merawat kehidupan mangrove di daerah sini."

"The community helps by carrying out maintenance and protecting the mangrove ecosystem in this area."

Moreover, PB mentioned that NGO-local community groups like LMDH were established to ensure mangrove conservation:

"Untuk lebih jelasnya, kan LMDH itu kan anak dari Perhutani bisa disebut begitu jadi antara Perhutani. Jadi, pengelolaannya untuk lapangan itu dipercayakan kepada LMDH."

"To put it simply, LMDH can be considered an extension of Perhutani. The field management is entrusted to LMDH."

The high scores of community participation, ownership and benefit to the community can align with Peter Blau's social exchange theory that explains the transaction where each side gains something while giving something in return [5]. This means that as the community feels that mangroves provide values to their lives, they become more motivated to protect and maintain them. It proves that the governance system not only emphasizes environmental conservation but also considers the local people's economic interests, which enhances their reliance and affection towards the mangrove ecosystems. This condition supports long-term mangrove sustainability.

This theory is supported by a statement from PB. He explained that local communities benefit economically and socially from these mangroves. The majority of local communities rely on the surroundings for fisheries, fishponds, seedling nurseries, tourism, and entrepreneurship. PH and DL stated that local communities can access the land under certain conditions, such as the requirement to manage the mangrove ecosystems:

"Silahkan kalau mau bikin untuk mata pencaharian sehari-hari... tapi tolong jaga kebersihan terus pertumbuhan pohon-pohonnya. Jangan diganggu."

"Izin dari desa juga ada, biar desa mengetahui bahwa saya ini pedagang. Menurut data LMDH, total warung itu 45 warung."

"People are free to use the land for their daily livelihood... but please keep it clean and nurture the trees."

"We also got permission from the local government, so that they acknowledge me as a merchant here. According to data from LMDH, there are 45 merchant stalls here."

This is further reinforced by the field observation, as there were many merchant stalls open during our visits, emphasizing how much the locals depend on their location and why they are willing to care for the mangroves in return.

Although the community participation score is high, the score for community involvement in decision and regulation making are noticeably lower, especially in regulation making. They seem to be contradictory since communities participate in negotiations and consultations, but they do not play a critical role in regulation formulation itself. This suggests that the community are actively involved in various activities in mangrove areas, but less influential in determining policies and regulation. This phenomenon shows that the participation level of the community is closer to the placation stage within the tokenism category, as explained by Arnstein's ladder of citizen participation theory [6]. The placation stage of participation allows people to have a voice by giving them opportunities to express their opinions and participate in consultations and committees. But the real control and authority over the final decision belong to those in power, which is the government. As a result, participation exists, but the governance power of this community remains limited. This finding aligns with interview data, in which community members of Tanjung Pasir are indeed invited for discussions and consultations concerning mangrove management, but the decision is made by the government, as stated by HJ and PH.

"Yang rapat paling usaha, paling pembenahan lahan. Paling lahan gitu. Jadi sekarang mana nih, pembenahan ekonomi. Keputusannya dari Perhutani."

"The meetings usually discuss businesses, land improvement, and economic development. The decisions come from Perhutani."

The score for participation of external stakeholders is also relatively high. Data of the field observation showed there are many signposts with company or school names on fields where mangroves were planted. Some stakeholders are involved in mangrove planting programs. Some parties are also involved in maintaining mangrove plants and even conducting research about them. In one of our interviews, BR mentioned that planting mangroves became a program at their school.

"Di sekolah itu kan ada kegiatan akhir semester. Nah, itu kegiatan berkembang menjadi kegiatan penelitian anak-anak."

"In school, mangrove planting is one of the end-of-semester activities. Occasionally, it also developed into research activities for the students."

This strong involvement of external parties shows that mangrove governance in this area depends not only on the local community, but also on the collaboration of multiple stakeholders. According to Ardiyanto et al., there are three types of stakeholders: main, key, and supporting stakeholders [7]. Stakeholders in Tanjung Pasir mangrove are categorized as supporting stakeholders, as they are parties who show concern and make indirect contributions in the management, but have no official authority in decision making.

4 Conclusion

In conclusion, Tanjung Pasir mangrove is governed by a hybrid management model between CBM and MSP, which can strengthen long-term sustainability of the mangrove ecosystem and provide an ideal local solution for the livelihood sustainability of communities, especially for those living in the Tangerang coastal area.

Future works may investigate more on the economic contribution mangrove ecosystems bring to local communities, including fisheries, ecotourism, and small businesses around the area.

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Synergies. The Case of the Vanoi Torrent Dam.

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Abstract

This paper explores the underlying reasons against the construction of a dam in the Vanoi Valley through a qualitative approach based on interviews with local stakeholders. The analysis draws on key theoretical perspectives from human geography, landscape anthropology, and environmental psychology. The words of the stakeholders reveal how perceptions of the territory are shaped by identity, emotions, and community-based values. These dimensions cannot be ignored when planning human infrastructure, especially when such interventions are highly intrusive, as in the case of a large dam. The study also reflects on the collective memory of the Vajont disaster, interpreted both as a historical trauma and as a form of cultural warning.

This perspective helps to explain how Italy's hydroelectric history continues to shape contemporary perceptions of risk and the level of trust in public institutions. The paper highlights how resistance to the dam is not merely technical opposition, but rather the expression of a vision of the future rooted in care for the place by way of cultural continuity and environmentally sustainable proposals. Within this perspective, eco-sustainable alternatives, such as the protection of resurgence springs (typical of northeastern Italy), emerge as key elements to be safeguarded within a framework of multilevel governance.

Keywords

Resurgence springs, place identity, territoriality.

1. Introduction

The recent reopening of the debate on the construction of a dam along the Vanoi torrent has brought renewed attention to an issue that intertwines environmental, identity-related and institutional dimensions. The project, relaunched in December 2022 by the Veneto Region through the commissioning of a feasibility study to the Consorzio di Bonifica Brenta, envisages the construction of the structure in Val Cortella, a lateral valley following on from the Vanoi Valley. Although morphologically distinct and not visible from the main settlements of the Vanoi, it remains an integral part of the same territorial and hydrographic system. At European level, pressure on freshwater resources is steadily increasing. The European Environment Agency reports that «water stress is already occurring in Europe ... it affects 20% of Europe's territory and 30% of the population every year» [1]. This broader context reinforces the need for integrated, climate resilient water management strategies, rather than isolated large-scale infrastructures. Its proposed location does not, however, lessen the concerns of the local population, as Val Cortella shares with the Vanoi the same geomorphological fragilities and the same historical memory of past flooding episodes.

The dam project is not new: it had already been rejected in the 1970s and 1990s due to the high instability of the slopes and the hydrogeological vulnerability of the area. Its re-emergence has been justified by the need to address the increasing water scarcity affecting the Veneto plain during the summer months. Nevertheless, communities in both Trentino and Veneto reacted with broad and cross-regional mobilisation, interpreting the project as a threat not only to the environment but also to local identity and community life. The memory of the Vajont tragedy remains a historical trauma as well as a warning for community planners [2]. In addition, recollections of the 1966 flood in Val Cortella have reinforced perceptions of risk and the need for prudent, participatory territorial management.

In 2024, opposition took on more structured forms: a petition promoted by the Committee for the Defence of the Vanoi Torrent gathered 13,493 signatures, while a 200-kilometre march on foot from Canal San Bovo to Venice revealed the connection between mountain and lowland communities along the entire Vanoi-Cismon-Brenta hydrographic system. These initiatives highlighted that the issue at stake is not merely an engineering project, but a model of water-resource management over multiple territories, requiring multi-level governance [3].

Within this context, our qualitative research based on in-depth interviews explores the deeper reasons behind opposition to the dam, moving beyond the already well-known technical aspects. The interviewees' accounts show how the relationship with the territory is shaped by identity-based, emotional, symbolic and community-rooted elements, and how such dimensions must be considered when planning potentially disruptive interventions. These interviews also shed light on alternatives proposed by local communities, such as the enhancement of resurgence springs (risorgive) [4,5], a distinctive feature of the hydrographic landscape of north-eastern Italy, and the search for shared solutions across the entire river basin.

2. The territory

2.1 The Vanoy Valley

The Vanoi torrent flows for approximately 25 km along the valley of the same name, before joining the Cismon River and subsequently the Brenta, whose waters eventually reach the Venetian lagoon. The main settlement of the valley is Canal San Bovo. In the upper part, in the locality of Caoria, there is a hydroelectric power plant.

Around 75% of the valley, including smaller lateral valleys such as Val Cortella, is classified as being at high or medium hydro-geological risk [6]. High-risk features include: steep slopes, active and dormant landslides, unstable alluvial fans, debris flows and potential flood zones along the Vanoi torrent and its tributaries. The most exposed settlements are Caoria, Canal San Bovo, Ronco, Cicona and the localities along the Lozen torrent. Medium-risk areas, located on the valley floor and mid-slopes, show widespread instability, shallow landslides and accelerated erosion. These elements cause concern among the local population, an attitude which is reinforced by the memory of the Vajont disaster and the 1966 flood that destroyed the village of Canal San Bovo and after reached Bassano del Grappa. [2]

Despite this fragility, the Vanoi Valley is today one of the few Alpine areas characterised by extremely low levels of urbanisation [7], with an environment that remains largely unspoilt with a low population density. The valley hosts endemic plant and animal species, and the Vanoi torrent flows along its natural riverbed, unaltered by artificial interventions – a rarity in contemporary Italy. Human-made structures exist exclusively to manage the flood risk without modifying the course of the torrent.

From an environmental perspective, the Vanoi is marked by extensive forest cover dominated by Norway spruce, larch and beech, in continuity with the nearby Lagorai range. Studies on Alpine forest landscapes [7] show that these areas retain a complex ecological structure, the result of historically low-intensity management. The valley's hydrography, shaped by the torrent and its tributaries, is characterised by cold, well-oxygenated waters typical of mountain basins with limited human impact [8].

Socially, the valley is home to a small yet cohesive population, distributed across small villages and hamlets. Research on the Trentino mountains [9] highlights how these communities maintain strong social capital, based on neighbourly networks, local associations and ritual practices linked to the seasonal cycle and territorial management.

The passing down of local knowledge and cultural practices are a major part of the landscape stewardship, as documented in studies on inhabited mountain regions [10].

The Vanoi has undergone a gradual economic transformation. Traditional agriculture, once central, survives today in reduced but in a strategic form for landscape maintenance, as shown in studies on Alpine agricultural multifunctionality [11]. Forest management remains a significant sector, supported by local enterprises and a long tradition of sustainable timber use [12]. In recent decades, tourism has centered on nature, hiking and tranquillity, consistent with models of soft tourism in the Alps [3]. The proximity of the Paneveggio-Pale di San Martino Natural Park reinforces this, promoting a conservation-based and participatory approach to territorial management.

Overall, the Vanoi Valley emerges as a territorial system in which environment, community and economy are deeply intertwined. Its well-preserved environmental features, strong social bonds and an economy rooted in landscape care contribute to shaping a solid and recognisable local identity, sustained by daily work in a long-standing relationship with the landscape.

2.2 The previous and avoidable Vajont tragedy

Three years before the flood that struck the Vanoi Valley, in 1963, the Vajont tragedy occurred [2], near the municipality of Longarone (Belluno). With around 2,000 victims of which 1,300 bodies were never recovered, it remains the most serious dam-related disaster in Italian history. At 22:39 on 9 October, approximately 260 million cubic metres of rock detached from Mount Toc and plunged into the artificial basin created by the SADE (Società Adriatica di Elettricità) dam. The dam itself remained intact, but the overtopping wave swept through Longarone and the villages of Erto and Casso. The toponym “Toc”, meaning “rotten” in the local dialect, reflected the population’s awareness of the slope’s fragility (an awareness ignored despite warnings from geologists and experts). The tragedy, now embedded in national memory, led to a revision of dam regulations and to greater institutional attention to the need for accurate technical studies and respect for territorial features[2].

2.3 Towards the resurgence springs

The Vanoi torrent, flowing into the Cismon and then the Brenta before reaching Venice, forms one of the main water arteries feeding the Veneto plain, an area that has for years suffered from summer droughts affecting agriculture, livestock, farming, industry and domestic use. Along the Vanoi‑Cismon‑Brenta system there are already storage basins, such as the dammed lakes of Val Schener and Corlo, as well as the resurgence springs, which have long been a fundamental water source and part of the local cultural heritage. The strategic relevance of these ecosystems is also recognised at European level. The EEA emphasises that «restoring wetlands and peatlands should be seen as an essential step to restore healthy, biodiverse freshwater ecosystems» [1]. The protection and revitalisation of resurgence springs therefore align with European priorities for nature‑based solutions and long‑term water resilience. Poor management of these resources has, over time, led to the need to request water from neighbouring territories such as Trentino.

The interviewees identified good management of water resources along the basin as an alternative to the dam, promoting horizontal and vertical synergies between local communities, municipalities, provinces, regions and the State [3].

The resurgence springs are among the most distinctive and delicate ecosystems of the northern Italian plains [4], where groundwater, forced upwards by lithological variations in the subsoil, resurfaces to form point‑like or linear springs. From a scientific perspective, hydrogeological studies on the aquifers of Veneto and Friuli show that this phenomenon is linked to the contact between permeable layers (gravels and sands) and less permeable layers (silts and clays), which force the water to emerge. The resurgence springs are therefore sensitive indicators of the state of aquifers and their recharge, and constitute a living archive of the hydrological dynamics of the territory.

The Ministry of the Environment emphasises that these environments are not only hydrogeological features but complex ecological systems characterised by cold, oxygenated and stable waters that host highly specialised plant and animal species [5]. The resurgence springs are biodiversity hotspots: hydrophilous mosses, macrophytes, rare invertebrates and fish typical of spring waters find unique conditions here. The thermal and chemical stability of the water creates stable microhabitats that are, however, extremely vulnerable to human pressures such as water abstraction, drainage, diffuse pollution and morphological alterations.

From a management perspective, the LIFE Risorgive Project [4] proposes an integrated approach combining hydrogeological protection, ecological conservation and cultural enhancement. The guidelines emphasise interventions such as river renaturalisation, removal of rigid canalisation, restoration of vegetated banks, control of invasive species and continuous monitoring of water quality. Sustainable management of the resurgence springs also requires the involvement of local communities and farmers, as many resurgence springs are historically linked to *fontanili*, traditional hydraulic structures that have shaped the agricultural landscape and supported rural economies. This heritage is well documented at the Museo delle Risorgive in San Pietro in Gu (province of Padua), established in 2012 following Regional Law no. 23/2009, "Initiatives for the protection of resurgence springs watercourses".

From a theoretical perspective, the resurgence springs can also be understood as identity-bearing places. Their presence has shaped settlements, agricultural practices, place names and local narratives. In this sense, the resurgence springs are water landscapes that intertwine nature and culture: physical elements that become territorial symbols. Their protection concerns not only ecological conservation but also the safeguarding of a cultural and landscape heritage that narrates the historical relationship between communities and their environment.

In summary, the resurgence springs are complex hydrogeological systems, high-biodiversity ecosystems and deeply identity-laden places. Understanding and managing them means recognising their dual nature: fragile and precious, scientifically significant and culturally rooted.

3. Literature review

3.1 Place Identity

Reflection on the resurgence springs introduces the concept of place identity [13], developed within humanistic geography and contemporary social sciences to describe how individuals construct essential parts of their identity through their relationship with the places where they live. Relph [14] showed that place is not merely a physical location but an existential experience that may be authentic or threatened by the loss of meaning produced by modernity. His distinction between place and placelessness highlights that territorial identity emerges when people recognise a place as their own, familiar and meaningful, and dissolves when spaces become interchangeable and rootless.

Tuan [15] deepens this perspective by distinguishing between "space", understood as openness and possibility, and "place", which emerges when space is lived in, named and inhabited. Place is the outcome of a process of emotional and symbolic sedimentation: it becomes such when people project memory, affection, routines and orientation onto it. In this direction, Norberg-Schulz [16] interprets place as the expression of a specific "spirit", an unrepeatable character arising from the interplay between physical form, history and human experience. The *genius loci* is not a metaphysical entity but the profound quality that enables inhabitants to recognise themselves in a landscape and to feel "at home".

More recent literature has expanded and further articulated this framework. Peng, Strijker and Wu [17] show how the concept has become multidisciplinary, encompassing psychological, sociological, political and cultural dimensions. Place identity is no longer only an affective attachment but a dynamic process involving narratives, practices, representations and conflicts. Maier [18] emphasises the political dimension of place: territories are not mere containers but spaces of belonging that define who is included, who is excluded, and which memories are recognised or marginalised. Territorial identity is therefore also a stake, a means of asserting continuity, rights and visions of the future.

Taken together, these contributions show that place identity is a complex and layered process in which territory, emotions, memory, symbols, practices and power intersect, as also confirmed by environmental psychology studies [15]. Understanding how people live and narrate their places therefore means understanding a fundamental part of their individual and collective identity.

In the case of the Vanoi dam, interviewees express concern about two main issues: on the one hand, the increase in humidity resulting from the presence of a large artificial basin nearby; on the other, the rise in precipitation which, in their perception, would exacerbate the instability of the slopes, already subject to a natural process of downward movement. In their interpretation, the more it rains, the more the slopes slide. European data confirm that extreme events are intensifying. The EEA reports that «intense rainfall has already increased in parts of Europe, leading to floods and growing flood risks» [1]. This reinforces local fears that intrusive infrastructures in highly unstable mountain environments may exacerbate hydrogeological vulnerability rather than mitigate it.

3.2 Upstream: hydraulic works and territorial identity

The relationship between local populations, dams and the environment is a complex issue that intertwines ecological, social, cultural and political dimensions. Large hydraulic works are never purely technical interventions: they reshape ecosystems, economies and territorial identities, often generating tensions between development visions and forms of local belonging. Academic literature shows that resident communities perceive dams not only in terms of environmental impacts, but as profound transformations of their "lifeworld".

Cernea [19], in his IRR model (Impoverishment Risks and Reconstruction), highlights how major hydraulic infrastructures entail risks of economic and cultural marginalisation, especially when communities are not involved in decision-making processes. This does not concern only forced displacement, but also the loss of familiar landscapes, the disruption of social networks and the transformation of traditional economic practices.

From an environmental perspective, studies such as those collected by McCully [20] and by the World Commission on Dams [21] show how dams profoundly alter river systems: they modify flows, temperatures, sediments and habitats, with cascading effects on biodiversity. These changes are not perceived solely by ecologists but also by inhabitants, who often interpret the river as part of their territorial identity. In many mountain communities, the river landscape is tied to everyday practices, family memories and forms of local knowledge that risk being compromised.

Relph [14] and Tuan [15] demonstrate that place is an experiential and symbolic construct: when an infrastructure radically transforms a landscape, it also transforms the sense of belonging. Local communities may perceive the dam as a threat to place identity, especially when the project is seen as external or imposed. More recent studies, such as those by Tilt, Braun and He [3], show that conflict arises not only from material impacts but from the fracture between technical knowledge and local knowledge.

Finally, historical memory plays a crucial role. In Italy, the Vajont remains a cultural reference that still shapes perceptions of risk and trust in institutions [2]. This demonstrates that the relationship between local populations, dams and the environment is always situated: it intertwines history, identity and landscape, and requires decision-making processes sensitive to territorial specificities.

3.3 Downstream: resurgence springs and territorial identity

The resurgence springs represent one of the most eloquent examples of how a natural element can become the focus of local identity. They are not only hydrogeological phenomena, but places where water, history and community practices intertwine producing a landscape that "speaks" to the people who reside in it. In this sense, the resurgence springs incarnate the idea of landscape as identity, as they do not simply define the morphology of a territory, they contribute to building belonging, memory and shared meaning.

Cultural ecology offers a valuable interpretative lens: communities do not experience water as a simple resource, but as part of a relational system that includes agricultural uses, rituals, local knowledge and everyday forms of care. The resurgence springs, with their clear and constant water, have historically supported valley economies, shaped settlements, guided paths and delimited fields. They therefore shape not only the environment but also social practices and collective narratives.

The concept of place identity helps explain why these places are perceived as indispensable. For Tuan [15], place emerges when space is lived in, named and inhabited: the resurgence springs become places because people project memory, affection and routines onto them. Relph [14] emphasises that place identity is fragile and can be threatened by works that break the continuity between landscape and lived experience. In this framework, the resurgence springs are not mere water points: they are identity "anchors" that root communities in their territory.

Turri [22] offers a decisive perspective: landscape is the stage on which social life unfolds, a theatre that shapes gestures, rhythms and relationships. The resurgence springs, in this metaphor, are essential scenic backdrops: places that orient practices, give meaning to paths and define what a community recognises as "its own". Altering them means changing the stage itself, modifying the relationship between inhabitants and territory.

Water landscapes also possess strong symbolic value: water emerging from the ground is perceived as origin, purity and continuity. It is water that "comes from within", carrying a sense of territorial intimacy. This explains why interventions that modify its course or appearance are experienced as threats not only to ecology but to identity.

In short, the resurgence springs are water landscapes that become identity landscapes: places where nature and culture merge to make the territory not only a space to inhabit, but an essential part of who people are.

3.4 Governance multilevel

The newly elected president of the Brenta Consortium, Martino Cerantola, elected in early 2026, decided to halt the Vanoi dam project, opting instead for alternative solutions such as managing existing basins and investigating groundwater resources. His election followed years of conflict between supporters and opponents of the project, which had led to the Consortium being placed under temporary administration in 2025. This decision is consistent with European recommendations. The EEA notes that «balancing demands from across different sectors clearly requires strong and integrated planning across different scales of governance» [1]. The Vanoi case therefore exemplifies the need for multilevel governance capable of integrating local knowledge, institutional responsibilities and basin-wide coordination. The dam project, discussed for nearly a century for hydroelectric and flood-mitigation purposes, had always been hindered by technical and economic issues, local opposition and the resistance of the Province of Trento. Despite a final push in 2023 by the previous President of the Veneto Region, Luca Zaia, the project never reached an operational phase.

With the Consortium's new direction, the dam now appears to have been definitively abandoned, thanks also to the consideration given to the population's opposition. This outcome reinforces the idea that such invasive projects must follow a logic of multilevel governance, capable of integrating institutions and local communities into decision-making processes [3].

4. Method

The research presented is qualitative in nature and is based on in-depth interviews conducted with several stakeholders directly involved in, or affected by, the proposed dam project. Since the strong opposition of the residents to the project was already well known, a qualitative approach was considered the most suitable means for exploring this position beyond technical aspects. In-depth interviews proved to be the most effective technique for reconstructing underlying reasoning and emotions, which revealed the details of relationship between inhabitants and their territory

In an initial phase, a literature review was carried out on the dam project and on the main historical records with academic references relevant to the case. Two documentary films were then examined: *Il racconto del Vajont* [23], which reconstructs the 1963 tragedy in detail using legal and historical sources, and *In cammino per l'acqua* [24], dedicated to the Vanoi dam case and to the eight-day march that began on 30 October 2024 in Canal San Bovo and ended in Venice, following the course of the Vanoi, the Cismon and finally the Brenta. The march involved residents of the Vanoi Valley and citizens from the various municipalities along the route, offering direct testimony of community engagement.

A set of guiding questions based on these records were constructed for the interviews . Through contact with the promoter of the Vanoi documentary and via word of mouth, key individuals to be interviewed were identified. Four stakeholders were thus involved: the Mayor of Imer (Daniele Gubert), the former Mayor of Canal San Bovo and promoter of the documentary (Angelo Orsingher), a member of the Vanoi Torrent Defence Committee residing in the valley (Flavio Taufer), and the current Mayor of Canal San Bovo (Bortolo Rattin). Despite the limited number of interviews, the interviewees' deep and long-standing knowledge of the case made it possible to capture both technical aspects and emotional and identity-related dimensions. The interviews, recorded and fully transcribed, were analysed manually.

4.1 Interviews

The aim of the interviews was to verify whether, beyond technical motivations, opposition to the dam was also rooted in an identity-based relationship with the territory, and to understand how this manifested itself.

Following the theoretical framework, the first section of questions concerned place identity: "In what ways has living in the Vanoi contributed to shaping who you are today?", "Which aspects of the valley do you feel most closely tied to your personal or family identity?", "Does the Vanoi Valley contribute to your personal or family identity? If so, how do you think the dam might alter this relationship?" The aim was to elicit rootedness, biographical narratives, memories and symbols.

The second section focused on the perception of landscape and change: "Which aspects of the Vanoi landscape do you consider indispensable? What emotions does the idea of these elements being altered by a project such as the dam evoke in you?" This part sought to explore perceptions and emotions, distinguishing between material and symbolic elements, and to bring out the *genius loci* [16].

The third section activated the anthropological dimension, investigating practices, rituals and community relations: "Which activities, traditions or community relationships do you think would be most affected by the presence of the dam? Can you give me some concrete examples?" The aim was to understand how the community uses the territory and to highlight the landscape as a social stage [22].

The final section explored perceptions of the future, shifting the focus from "what people are against" to "what they are for": "What future do you imagine for the Vanoi?", "Which values do you believe should guide decisions concerning its territory?" This part aimed to elicit values, visions and priorities.

As is typical of in-depth interviews, the questions served as a flexible guide, adapted accordingly to each conversation [25].

4.2 Analysis

The interviews were analysed through open coding, later organised into theoretical macro-categories. The analytical grid was structured into macro-categories, sub-categories and observable indicators.

From the macro-category *place identity*, the following sub-categories were derived: biographical rootedness (indicators: childhood memories, family genealogies, "I grew up here", generational continuity); symbolic identity of place (indicators: "the Vanoi is…", metaphors, recurring images, *genius loci*); emotional attachment (indicators: affection, pride, sense of home, safety, familiarity).

From the macro-category *perception of landscape and change*, the sub-categories were: indispensable landscape elements (indicators: forests, water, silence, visual continuity, fauna, naturalness); aesthetic and symbolic values (indicators: beauty, harmony, authenticity, landscape as heritage); emotions linked to change (indicators: fear, sadness, anger, concern, sense of loss).

From the macro-category *social and community practices*, the sub-categories were: everyday practices (indicators: walking, wood gathering, agriculture, fishing, use of paths); community traditions and rituals (indicators: festivals, transhumance, associative activities, local narratives); social relations and community capital (indicators: mutual help, neighbourly networks, sense of community).

From the macro-category *values and future*, the sub-categories were: guiding values (indicators: environmental protection, cultural continuity, local autonomy, prudence); desired development models (indicators: slow tourism, agriculture, craftsmanship, non-industrialisation); fears for the future (indicators: depopulation, loss of identity, community conflict);

alternative proposals (indicators: project ideas, eco‑sustainable solutions, shared resource management). Interview quotations are presented using guillemets «…».

5. Identity *of* and *in* place

The analysis of the four in‑depth interviews shows how the theoretical concepts discussed in the previous sections, place identity, genius loci, territoriality and multilevel governance, take shape in the experiences, emotions and narratives of the people who live in or administer the valley. The testimonies reveal how the relationship with the Vanoi and Val Cortella is rooted in local life , collective memories and everyday practices, and how the dam proposal is interpreted through these identity‑based lenses. The interviews therefore make it possible to grasp the complexity of the conflict, revealing dimensions that go beyond technical aspects and concern cultural continuity, care for place and perceptions of the future.

5.1 The "neighbour"

The first interview was conducted with Daniele Gubert, Mayor of Imer, a municipality bordering Canal San Bovo. His words convey a strong sense of loss: the disappearance of 8 km of freeflowing torrent would mean the destruction of a unique ecosystem. He speaks of a «major subtraction» and of the risk of isolation for the hamlet of Bellotti, which «would be cut off by the lake […] and would lose an important access route». The valley, which residents were strongly bound to for their identity, would risk becoming an artificial and degraded environment. This perception echoes in literature on place identity [13] and on the vulnerability of mountain cultural landscapes [11, 12].

The loss is not only physical but also functional: the valley would become a «reservoir for agriculture», erasing activities such as sport fishing and kayaking. Gubert stresses that «a wild torrent […] would be turned into a large basin», putting the marble trout, «a species at risk of extinction», in jeopardy. The landscape, too, would be transformed: from a green, living valley to a «dead and grey» one, a «lunar landscape […] made of grey silt». This transformation recalls Relph's notion of placelessness [14], the loss of place identity when a landscape is rendered artificial and homogenised.

The contrast between the present state and the projected future is stark. Today, the valley offers a natural experience dominated by the sound of the freeflowing torrent: «the prevailing sound is that of the torrent running without barriers». The dam would instead introduce a negative visual and climatic impact, exacerbated by the transport of materials and increased humidity. Gubert notes that «the more it rains, the more these [slopes] slide», showing how risk perception is rooted in local knowledge, in line with environmental psychology [15] and the literature on Alpine geomorphological fragility [10].

His emotional bond with the valley exemplifies topophilia [15]. The valley is not perceived as a resource but as a place with intrinsic value: «I have walked through Val Cortella many times, taking friends and journalists to show it to them». Collective mobilisation is an expression of this attachment, confirming what Peng, Strijker and Wu [17] and Maier [18] observe about the political and emotional dimensions of territorial identity.

The interview also highlights a conflict between decision‑making scales. Gubert interprets Veneto's approach as «trampling on the history, traditions, reality and environment of someone else's home». Val Cortella, being remote and sparsely inhabited, risks being treated as a sacrificable place. This dynamic recalls analyses on conflicts between local governance and top‑down decisions [3], and the literature on large infrastructures that emphasises the marginalisation of peripheral communities [19, 20, 21].

Attachment also emerges as historical rootedness: the reference to the 1966 flood shows how collective memory is intertwined with the morphology of the torrent. The fear that the valley will become unrecognisable indicates that physical change would destroy the reference points needed to feel «at home»: «an Alpine V‑shaped valley would be turned into an immense reservoir». This relationship between memory, landscape and identity is consistent with Armiero [2] and humanistic geography [14, 15].

Gubert's assessment of hydropower is critical: the dam is an «old and wrong idea». The example of the Schener dam, «with less than half of its original capacity», shows how lack of maintenance turns valleys into «disposable» places. Alternatives such as managing groundwater would avoid new heavy construction in the mountains. This perspective aligns with sustainable solutions proposed in studies on resurgence springs [4, 5] and with the logic of multilevel governance [3].

The Vanoi dam case is a complex example of multilevel governance. Veneto attempted to «impose something from above», while Trentino asserted the right to «decide in our own home». The definitive cancellation of the project, announced on 25 March 2026, is the result of citizen mobilisation, confirming what Tilt, Braun and He [3] highlight about the importance of participation in major projects and the need to integrate local knowledge with technical expertise.

5.2 The former Mayor

The second interviewee was Angelo Orsingher, former Mayor of Canal San Bovo and a central figure in the mobilisation against the dam. His bond with the valley is profound: «I was born there in the valley […] I have a very strong emotional connection». His testimony fully embodies place identity [13] and topophilia [15], rooted in decades of administrative and personal life.

Orsingher describes Val Cortella as a unique place: «the only place where you can see a torrent flowing for 8–9 km without any kind of reservoir». The dam would represent an irreversible rupture: «an intervention like this would greatly change the microclimate», bringing more humidity and slope instability. The landscape would become «barren, ugly», as happens at Lake Corlo when it is emptied. This transformation recalls Relph's placelessness [14], the loss of identity when a place is artificialised and rendered unrecognisable.

The valley is also a cultural landscape in Turri's sense [22]: a «theatre of life» shaped by activities linked to the forest, mountain pastures and craftsmanship. However, depopulation and ageing have weakened social networks. Orsingher recalls that «the mountain pastures began to disappear after the '60s and '70s», confirming what Corona et al. [7] and studies on inhabited mountain regions [11, 12] observe about the transformation of Alpine rural landscapes and the loss of traditional practices.

The dam would entail significant risks: «dams drive people away from their territory», as shown by the cases of Corlo and Sospirolo. This dynamic aligns with Cernea's IRR model [19], which highlights how major infrastructures can generate marginalisation, loss of social capital and disruption of community networks. The literature on large dams [20, 21] also shows that impacts are not only ecological but deeply social.

The geomorphological fragility of Val Cortella is central: «the Province's maps place it in a high-risk context». The 2010 landslide and the collapse of the historic road show that the territory is already vulnerable. The reservoir would «further weaken» the slopes, «similar to what happened at Vajont». The memory of the disaster, as Armiero [2] notes, continues to shape risk perception and trust in institutions, becoming a cultural reference that guides collective choices.

Orsingher also highlights a widespread sense of resignation: «if they want to do it, they'll do it», especially among the elderly. Yet the march for water and the petition created a network of solidarity: «an extraordinary feeling of connection, of wanting to help». The metaphor of the water bottle exchanged between Coppi and Bartali becomes a symbol of interterritorial cooperation, in line with studies on bottom-up governance and community cooperation [3].

Politically, he denounces the lack of dialogue: «we found out from the media». Governance appears fragmented, in contrast with the multilevel model advocated by Dematteis and Governa [3] and with the recommendations of the World Commission on Dams [21] regarding the need for participatory and transparent decision-making.

Alternatives such as resurgence springs are seen as more sustainable solutions [4, 5], consistent with a water-management model that enhances existing resources and reduces environmental impact. This perspective fits within a vision of a territory that does not want to be sacrificed but regenerated.

Finally, Orsingher imagines a future based on quality of life: «clean air, water flowing from the spring, a healthy environment». Yet the valley is also threatened by the dumping of polluted materials from Trento: «they bring rubbish here […] the valley is the green heart of Trentino». His testimony shows how defending the Vanoi is an act of care towards a fragile and identity-bearing territory, in line with the literature on territory and local belonging [18].

5.3 The genius loci

The third interview involved Flavio Taufer, a former teacher and environmental activist. His bond with the valley is deep: «I know this valley and all its surroundings like the back of my hand». His narrative embodies place identity [13] and topophilia [15], rooted in years of daily engagement with the territory and civic participation.

Taufer spontaneously introduces the concept of *genius loci*: «every place has its own genius […] made of air, water, earth, people». This interpretation directly recalls Norberg-Schulz's phenomenological reading [16], according to which every place possesses a specific, recognisable and unrepeatable character arising from the interplay between morphology, natural elements and human experience. Val Cortella is perceived as a unique place, «not lived like other localities in Primiero», and therefore «unique and rare». The dam would represent the irreversible loss of this identity: «the genius loci would leave, it would disappear». The transformation of the landscape into an artificial space recalls Relph's placelessness [14], the loss of authenticity and recognisability.

The valley contains the last stretch of free-flowing torrent in the area: «what remains to us is only one free-running torrent». The reservoir would entail «the erasure of a considerable habitat» and the transformation of the landscape into «a huge bathtub». This image is not only ecological but identity-related: as Tuan [15] and Maier [18] show, water landscapes are central to the construction of belonging, and their artificialisation can generate feelings of loss and disorientation.

Taufer emphasises the fragility of the territory: «the hydrogeological risks are obvious, even a child would understand». The valley is «remote, isolated», and this very condition makes it vulnerable to interventions perceived as aggressive. The dumping of inert materials from Trento represents a «new emergency», with materials «partly contaminated» deposited «in an area at absolute risk of flooding». This dynamic recalls analyses by McCully [20] and the World Commission on Dams [21] on marginal areas treated as "sacrifice zones", where infrastructures and waste are placed in territories perceived as peripheral or less defended.

Despite this, mobilisation is strong. Taufer recalls the march of 6 October, which involved «groups of people» along the entire Brenta, creating «a strong alliance of intentions». This interterritorial network confirms what Dematteis and Governa [3] observe about bottom-up governance and the capacity of local communities to activate horizontal cooperation. The march thus becomes a concrete example of territorial social capital, in line with studies on the Trentino mountains [11, 12].

Emotions are central: fear, indignation, but also responsibility towards the future. Taufer addresses students: «you will be the ones who will have to deal with what we old folks have managed to save». This intergenerational dimension recalls the literature on collective memory and the role of environmental traumas in shaping risk perception, as shown by Armiero [2].

Finally, he imagines a future based on protection: «a serene oasis of peace, where nature can reclaim itself». Val Cortella is «a heritage to be handed down to you for the future». His testimony shows how the struggle against the dam is a cultural and symbolic commitment to preserve the last free-flowing torrent of the Alpine arc, confirming the centrality of landscape as the stage of collective life [22].

5.4 The Mayor

The final interview involved Bortolo Rattin, Mayor of Canal San Bovo. His perspective is institutional and cautious, yet deeply rooted in the territory. He describes the valley as «very peripheral […] but also intact from an environmental point of view», with an economy historically linked to the forest: «the main activity has always been linked to the forest». However, the valley is marked by depopulation and ageing: «in the 1980s it had 1,900 inhabitants, now we are 1,480». This dynamic confirms studies on inhabited mountain regions, where demographic fragility intersects with the resilience of social capital [11, 12].

The dam is described as «hypothetical», since «there are no elements that would allow it to be built». The proposed location, «near the confluence between the rivers Cismon and the Vanoi», would not be visible from the valley, but the main issue concerns microclimate and safety: «such a large mass of water would negatively influence the microclimate», increasing «rainfall and humidity». The Mayor recalls the presence of «a millenary landslide» moving «2 cm per year», which would accelerate with increased humidity. This attention to geomorphological vulnerability echoes the literature on risk perception and the relationship between mountain populations and slope instability [15, 10].

A distinctive element is the internal division within the population: «the population of the Vanoi is split approximately fifty-fifty». While those in the peripheral hamlets «do not perceive it as a problem», opposition is primarily driven by environmental organizations, many of which are external to the region. This dynamic confirms that territorial identity is plural and layered, as shown in studies on place identity and territorial belonging [13, 14, 15, 18].

Rattin acknowledges that the dam would alter some aspects of the landscape, but believes the visual impact would be limited: «not being visible, not even reachable». However, microclimate and safety remain critical points. While his position lacks the emotional intensity of the other interviewees, it is equally well-rooted: the priority is «the safety of the territory». This attention to continuity and landscape protection recalls Turri's perspective on landscape as the stage of social life [22].

The Mayor also addresses the question of alternatives: «maintenance of the existing reservoirs» and «alternative irrigation techniques» could reduce the need for the dam. He also mentions the issue of resurgence springs, confirming that «Mezzalira is very knowledgeable about alternatives». Giustino Mezzalira is a forestry specialist, hydrologist and science communicator from the Veneto region, who plays a central role in safeguarding local resurgence springs and promoting sustainable water management in Veneto. His technical authority has made him a key voice in the public debate on the proposed Vanoi dam. This openness fits within the framework of multilevel governance [3] and the sustainable water-management proposals found in the literature on resurgence springs [4, 5].

Politically, Rattin denounces the lack of communication from the Consortium: «we found out from the media». The Province of Trento expressed a «strong opposition, through official letters and a unanimously approved motion. The Mayor stresses that «there must be an agreement between the Province of Trento and the Veneto Region». This fracture between institutional levels recalls conflicts between top-down decisions and local autonomy described by Dematteis and Governa [3] and, more broadly, the literature on major infrastructures and participation [19, 21].

Finally, Rattin imagines a future centered on quality of life and repopulation: the co-living project has brought new families to the valley, attracted by the possibility «for their children to move around the village independently». However, the greatest challenge is cultural: «I have to fight demotivation». The valley needs to «re-motivate people» and stimulate greater proactivity. This vision is consistent with studies on local development in mountain areas, which emphasise the decisive role of social capital and community initiative [11, 12, 13].

Rattin's testimony portrays a valley suspended between fragility and potential, between environmental risks and a desire for renewal. The dam thus becomes a prism through which to read identity, governance, safety and the future of the mountain community.

Conclusions

The analysis of the four interviews shows that opposition to the Vanoi dam is not merely a technical disagreement but the expression of a deep, layered and identity-based relationship between the community and its territory. There is a clear convergence in these accounts, portraying a territorial system where the environment and social memory are deeply intertwined with future aspirations, a finding that confirms the study's theoretical framework

The interviewees describe the Vanoi as an integral part of their biography and identity, in line with the literature on place identity [13, 14, 15]. Childhood memories, family genealogies, everyday routines and traditional activities anchor people to the landscape, while the torrent and the valley take on the role of meaningful places endowed with a specific character linked to the *genius loci* [16]. The dam is perceived as a threat to this identity-based continuity rather than as a simple infrastructural intervention.

The Vanoi landscape is experienced as an aesthetic, symbolic and emotional heritage.The interviewees place great value on the natural state of the torrent, the silence, the visual continuity of the slopes, the presence of wildlife, and the rare quality of a still free-flowing stretch of water, The possibility of altering these elements generates intense emotions: fear, sadness, concern, but also a sense of responsibility, confirming the affective dimension of the relationship with the place [15]. In particular, Taufer's reflection on the *genius loci* and Gubert's image of a «lunar landscape» show how landscape perception is deeply embodied.

The memory of Vajont, recalled spontaneously by all, acts as a cultural trauma and as a lens through which risk is interpreted, in line with Armiero [2]. It shapes perceptions of territorial vulnerability and fuels distrust towards projects perceived as external or imposed. The millenary landslide mentioned by Rattin and the instabilities recalled by Orsingher reinforce this sensitivity.

The Vanoi also emerges as a lived landscape where walking, fishing, wood gathering, associative activities and community rituals form a vibrant social fabric, consistent with the idea of landscape as the stage of collective life [22]. The interviews confirm the presence of strong social capital, already highlighted in studies on the Trentino mountains [11, 12], which translates into cohesion, mutual support and the capacity for mobilisation. The march of 6 October, mentioned by Taufer, and the interterritorial network described by Orsingher are concrete examples of this.

The interviewees share a vision of the future based on environmental protection, cultural continuity and slow development, consistent with models of soft tourism and local development [3]. The dam is perceived as incompatible with this horizon, while the resurgence springs are identified as a strategic resource to be enhanced, in line with literature emphasising their ecological fragility and identity value [4, 5]. The alternative proposals: the maintenance of existing basins, groundwater management, efficient irrigation techniques show a willingness to contribute to shared, non-oppositional solutions, consistent with the logic of multilevel governance [3].

The Vanoi case suggests the need for interdisciplinary approaches capable of integrating ecological, identity-based, emotional and historical dimensions. Three directions emerge strongly: deepening the role of collective memory in risk perception and institutional trust, as shown by references to Vajont; valuing local knowledge as a cognitive resource often underused in technical processes; studying forms of community mobilisation in mountain areas, where social capital and territorial identity play a decisive role. These directions require qualitative and participatory methodologies capable of capturing the lived dimension of territory.

The case also highlights the urgency of territorial policies that recognise the complexity of local systems and value community participation. Several strategic orientations appear particularly relevant: adopting genuinely multilevel decision-making processes capable of bridging the gap between institutions and communities [3]; promoting sustainable water-resource management through the restoration of resurgence springs and the protection of groundwater [4, 5]; recognising landscape as a form of cultural and identity heritage, as well as a physical resource; integrating local knowledge into planning processes to enhance the legitimacy and sustainability of decisions.

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Water Waste in Agricultural Practices

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Abstract
Water shortage is becoming an increasingly important problem due to climate change, population growth, and rising water demand. In Türkiye, false irrigation methods and uneven dispersion are the main reasons. For this reason, understanding the reasons behind water waste in agricultural areas is essential for sustainable water management. The study aims to examine how traditional irrigation methods, unsustainable crop selection, and lack of awareness increase water consumption in rustic areas. The project's goal is to focus on the solutions that can be useful for water waste in agriculture in Türkiye. The working hypothesis is that poor irrigation practices are the major factors to water waste. The research will be conducted through data analysis based on experiments and the systems designed by our team. Collected data will be conducted to determine the most beneficial solutions to prevent water waste in agriculture. Besides these projects, our team will be making a website in order to reduce water waste caused by improper plant selection and irrigation practices. The expected outcome is to raise awareness and provide a clear understanding of the scale causes of water waste in agriculture, contributing to feature sustainable water policies and strategies.

Keywords
Water Conservation, Efficient Irrigation, Sustainable Agriculture, Enviromental awareness

1.Introduction

Although nearly 70% of the Earth's surface is covered by water, only 2.5% of it is fresh water, and the vast majority of that is locked in glaciers and polar ice [18]. Accessible fresh water in lakes, rivers, and reservoirs accounts for a mere 0.1% of the planet's total freshwater potential [16]. According to the UN Sustainable Development Goals Report 2024, roughly half the world's population experienced water scarcity for at least part of 2022; some 2.2 billion people lacked access to safely managed drinking water, and 3.5 billion could not access safely managed sanitation [17]. Türkiye's situation is particularly concerning: with only 1,555 m³ of available fresh water per person
per year, Türkiye already falls into the "water-stressed" category [14]. As the population grows, that figure is projected to drop to 1,000 m³/year by 2030 — placing Türkiye firmly on the path toward becoming a water-scarce nation [7], [15]. Regional imbalances compound the problem: the Marmara region is home to 28% of the country's population yet collects only 4% of total surface water, and in several basins — including the Menderes, Ergene, and Konya — water extraction already exceeds the capacity of those sources to replenish themselves [14].

Globally, agriculture accounts for approximately 72% of all freshwater withdrawals, making it by far the largest water-consuming sector on the planet [8]. In Türkiye, the picture is similar: 75% of consumed water goes to irrigation, while domestic use accounts for 15% and industry for 10% [12]. Conventional irrigation systems deliver an average of 4 litres per second per hectare; modern sprinkler and drip systems reduce that to just 1.2 litres — delivering a two-thirds reduction in water use [12]. Greenhouse farming, while enabling more controlled water delivery than open-field cultivation, carries its own water intensity challenges. The year-round, high-density production cycles typical of greenhouses increase total water demand per unit area — and unless equipped with modern drip systems, they can perpetuate significant wastage.

Climate change is expected to intensify the global water cycle, increasing both the frequency and severity of droughts and floods year after year [9]. Türkiye is among the countries most vulnerable to these impacts: average temperatures have been rising steadily since the 1990s, precipitation patterns are shifting, and in parts of the Marmara, Aegean, Central Anatolia, and Southeast Anatolia regions, groundwater levels in some wells have dropped by up to 100 metres [14], [16]. The Global Water Monitor 2024 report found that global water reserves fell for a fifth consecutive year, extreme dry periods are multiplying, and flash flood and flash drought events are intensifying [18]. Studies also show that 1,000 out of 2,000 monitored lakes worldwide experienced a 40–45% decline in water volume over the past 20 years — a trend visible in Turkish lakes such as Lake Tuz, Lake Burdur, and Lake Eğirdir [15].

The UN World Water Development Report estimates that approximately 1 billion people in urban areas are already facing water scarcity, and that number could climb to 2.4 billion by 2050 [17]. In Türkiye, water demand by 2025 was projected to reach three times the current consumption level, with regions such as Thrace, Central Anatolia, and Western Anatolia potentially facing severe shortages [7]. Taken together, these data points make clear that water conservation is no longer a matter of choice — it is an existential necessity [6]. The transition to modern irrigation technologies (especially in agriculture and greenhouse farming), widespread adoption of water-efficient practices, robust resource protection policies, and integrated water management frameworks will all be decisive in navigating one of the most critical transitions facing both Türkiye and the wider world [8], [14].

1.2 Problem Statement

In greenhouses, a significant portion of irrigation water is not absorbed by plants. Instead, this water either evaporates from the soil or is released into the atmosphere through plant transpiration. However, the transpired water is currently lost without being collected or reused, leading to unnecessary water waste. At the same time, irrigation systems often require frequent watering, which further increases water consumption. Despite the growing need for sustainable agricultural practices, there is still no integrated system that both reduces irrigation frequency and recovers the lost water for reuse. This creates an important challenge in terms of water conservation and efficient resource management.

1.3 Research Gap

Water use in greenhouse production in arid and semi-arid regions is significantly high, primarily due to evaporative cooling systems and plant transpiration processes. Within this context, two main approaches have been addressed in the literature: (i) physical recovery of moisture from greenhouse air through condensation, and (ii) reduction of water consumption through irrigation management strategies.

Regarding the first approach, several studies have investigated the potential for recovering water by condensing moisture from greenhouse air. For instance, Lovichit et al. [1] demonstrated that water vapor from greenhouse exhaust air can be recovered through condensation, and that this method can significantly reduce water use, particularly in semi-arid climates. Similarly, studies on closed greenhouse systems have shown that water lost through evaporation can be recaptured and reused via condensation-based humidity control systems [2]. However, the majority of these studies focus primarily on the physical and thermodynamic aspects of water recovery, while the interaction between recovered water and irrigation management has received limited attention.

The second approach, irrigation strategies, generally aims to reduce plant water consumption. Studies examining greenhouse climate control and evapotranspiration processes indicate that water use is strongly influenced by environmental conditions and irrigation regimes [3]. Nevertheless, these studies predominantly focus on minimizing water input and do not consider the recovery and reuse of water lost from the system.
Therefore, it can be observed that there is a limited number of integrated studies that simultaneously address moisture-based water recovery and optimization of irrigation frequency and strategies [5]. In particular, there is a notable lack of research quantitatively evaluating the integration of recovered water into irrigation regimes and its impact on overall water use efficiency. This highlights the absence of a holistic approach to water management in greenhouse systems.

Furthermore, the existing literature on greenhouse water management is largely dominated by technical and engineering-oriented studies. There is a lack of research focusing on school-based, student-participatory, and practically applicable models (such as "WaterLife"-type systems). Most existing studies are based on laboratory experiments, commercial greenhouse applications, or simulation models, while educational and application-oriented frameworks remain underexplored.
For this reason, studies that integrate both condensation-based water recovery and irrigation optimization, while also developing practical and education-oriented models, are expected to make a significant contribution to the literature.

2. Brief Literature Review

Transpiration is a process which water is drawn from the roots and released as vapor[10].This process is important for the transportation of minerals and water from the soil to the leaves[11].It also helps the plant to regulate it's temperature[10]. Helping the plants to do transpiration better would be beneficial because then the plants would require less water to grow. While approximately 75% of the water consumed in Türkiye is used for irrigation, greenhouse farming provides more controlled water consumption compared to open-field agriculture; however, difficulties regarding water usage still occur. Therefore, growing alternative crops instead of certain plants in agriculture would be beneficial. As of some examples to some plants that uses a lot of water especially compared to their alternatives; The yearly average amount of water used for Apricot is 1,121.4 mm. Apricot starts to grow at the 3rd month (March) and completes its growth in the 9th month (September)[12]. As an alternative, we can grow Fig which uses ~700 mm of water. Fig needs much less water than apricot and is very well suited to the hot, dry summer[12].The yearly average amount of water used for Citrus is 824.7 mm. Citrus is a perennial plant, and its active water consumption period in this guide is calculated from the 3rd month to the 11th month[12]. As an alternative, we can grow Wine Grapes which uses 515.4 mm of water[12]. Beside of these plants, plants with exceptionally high transpiration rates, such as Eucalyptus, Willows, and Sunflowers, usually needs more water because the vapor that the plant had produced not being reused[11].These species generally thrive in water-rich environments because of their water usage that is more than the average plant.Leafy vegetables such as *Lactuca sativa* have high water demands because they have bigger transpiration rates due to such features like shallow root system and large leaf surface areas[13].Studies show that *Lactuca sativa* can contain up to 90–95% water by fresh weight, reflecting its physiological structure[13].Efficient water management can improve water use efficiency while minimizing the water that is lost on transpiration process[8].Additionally environmental factors such as temperature, humidity, and soil type significantly influence the overall water consumption of leafy vegetables and plants[11].Although these plants are using high amounts of water,Water vapor recovery in greenhouse systems has been investigated in several experimental studies in order to reuse the water vapor.In the most important experiments about this topic we usually see pipes being used to transport the humid air.These studies collectively demonstrate that greenhouse humidity—primarily generated by plant transpiration—can be treated not only as a climate control challenge but also as a recoverable water resource through engineered condensation systems.And also a different way to save water which is essential especially for dry regions is deficit irrigation[8]. Deficit irrigation strategies have been extensively studied as a means of improving water-use efficiency while having yields of acceptable quality to save water and use less amounts[8].Many studies in this topic shows that regulated deficit irrigation is a very beneficial way to save water and in some cases it even helps the plant to enhance crop quality[8].These results shows that deficit irrigation is a logical strategy to save water and also to keep the agricultural activities going on the dry, barren regions[6], [7], [9].

3. Purpose of the Investigation

The aim of this investigation is to collect water lost by *Lactuca sativa* plants through transpiration and make it reusable for greenhouse use, while comparing different irrigation frequencies and methods to evaluate their effects on plant growth and sustainability. It also aims to develop methods such as websites to raise farmers' awareness about water waste in agriculture.

4. Research Questions

1. How effective is a student-designed transpiration water recovery system in reducing water use while growing *Lactuca sativa* in a school laboratory?

2. Can the water released through *Lactuca sativa* transpiration be efficiently collected and reused as irrigation water in greenhouse cultivation systems?

3. Is it possible to design a simple, low-cost, and effective setup that can collect water produced through *Lactuca sativa* transpiration under greenhouse conditions?

5. Methods and Material

5.1 Experimental Method 1

In this experiment, a greenhouse model simulating greenhouse conditions was used. Within the scope of the study, 5 *Petroselinum crispum*, 5 *Lactuca sativa* , and 5 *Allium cepa* were cultivated. A drip irrigation system was preferred for watering, and all plants were irrigated with 10 ml of water every two days at

13:00. All plants were maintained under identical environmental conditions (light and temperature) and were observed regularly. Soil moisture was monitored consistently using a moisture meter, and care was taken to maintain it at approximately 70%. The duration of the experiment was determined as three weeks, during which plant growth was monitored and recorded.

Figure 1, plants that we planted

Figure 2, plants in greenhouse

5.2 Experimental Method 2

In this experiment, the condensation method was used to investigate water conservation. A total of 20 *Lactuca sativa* were used in the study 5 were used in the control group and 15 in the experimental group. In order to simulate greenhouse conditions, plastic bags were placed over the pots containing the plants. One plastic bag was used for every five pots to create a micro-greenhouse environment.
Irrigation was carried out by applying 10 ml of water per plant in each application to both the control and experimental groups. Soil moisture was regularly monitored using a moisture meter, and efforts were made to maintain the moisture level at approximately 70%. The experiment lasted for three weeks, during which plant growth and water consumption were systematically monitored.

Figure 3, the amount of transpiration of plants

Figure 4, plants in the control and experimental groups

Figure 5, Experimental and control groups on day 2 of the experiment

Figure 6, The experimental group and control group that we used to measure the amount of sweating.

6. Findings

This study demonstrates that a condensation-based water recovery system can significantly contribute to reducing irrigation water demand in *Lactuca sativa* cultivation under controlled greenhouse conditions. The experimental results indicate that approximately 28–38% of the water lost through transpiration can be successfully collected and reused. When this recovered water is reintegrated into the irrigation cycle, it leads to an overall reduction of 15–22% in external water consumption.

The findings highlight that even a simple and low-cost setup, consisting of polyethylene (PE) bags and basic condensation and collection components, can function effectively as a water recycling mechanism. The system not only captures transpired water but also ensures that the collected condensate remains clean and free from soil-related contaminants, making it suitable for reuse in irrigation.

The efficiency of the system was found to be influenced by environmental conditions, particularly temperature. Optimal performance was observed within a range of 19–24°C, where condensation rates and water recovery were at their highest. The average recovery of approximately 32.5 mL (± 4.5 mL) per plant demonstrates the consistency of the system and supports its potential scalability.

7. Discussion & Conclusion

According to the experimental findings, condensation was observed in the setups where a greenhouse system was created using plastic bags. This process maintained the soil's moisture balance, allowing the 5-day irrigation cycle to achieve an equivalent moisture level as daily watering. Consequently, the greenhouse effect minimized moisture loss and significantly reduced the frequency of irrigation required.

8. Recommendations

The goal of this project was to find ways to conserve the limited amount of water our world has and by doing this we would raise awareness among people about how water should be treated like any other precious gem would. We, as team Waterwise from Türkiye, have suggestions that we think will help turn these ideas solid, rather than just staying on paper. We believe that for a sustainable and healthy world, every single person on this planet has a responsibility to fulfill. Whether it be farmers, teachers, researchers or governors, we should all take part in this act that aims for a common goal: making a world we can safely live in.

We think that farmers and greenhouse operators should use the data we have collected in our project and pick a watering plan that will be chosen according to the growing conditions and needs of the plant. This can be done with the help of the website we have created called “Waterwiseturkiye.com”. With just this change we can increase the amount of water that is going to be saved. Another easy suggestion is to collect the water that plants in greenhouses create by transpiration. Which was the main experiment in our project and was proven to be helpful.

Another suggestion is for the teachers and academic assistants that are in charge of curriculum design. Now that we have proven that even an experiment done by high schoolers can cause a change and raise awareness within our peers, we think it will help reach many more people if these kinds of experiments were to be included in the lesson plan.

Our experiment was done with just one type of vegetable which was *Lactuca sativa*, which did create water by transpiration but if these types of experiments and researches was done with more plants or other conditions that could be tested it would help broaden our knowledge on plant transpiration and ways we can save water.The system we made for the greenhouse in our experiment did its work. But if we want to make the greenhouses save even more water, greenhouse companies should create more intricate systems. This would make it easier for farmers to use and help the environment.

We did this project under an Erasmus+ title. And there are many more Erasmus plus projects that have been done or are waiting to be made. The foundation we built for our project can be redone and be made better. Which is the main reason why these types of projects are done in the first place. To improve ideas. We cant make ideas work if we cant make people believe it . For this to happen; NGOs and environment protection associations should take a step to form awareness campaigns that will help people realize the problem and get taught the solutions for it.

Although these suggestions will work on their own but the best way to make them last is to make them be backed up by legal organizations and the government. İf the government can fund these projects, farmers, awareness campaigns; it will increase the amount of people who contributes to the sustainable life style. Also some policies can be added regarding the ways to save water and how irrigation systems are supposed to be used. Having a legal base for these rules would help more people follow them.

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