Deliverable: D.1.4.1

CATALOGUE OF THE MITIGATION SOLUTIONS AVAILABLE IN THE 4 DIFFERENT TOPOGRAPHICAL AREAS.

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TABLE OF CONTENT

EXECUTIVE SUMMARY

This deliverable is a part of the Activity 1.4 and presents a catalogue of Nature-based Solutions (NBS) flood risk management applicable to four distinct topographic areas: urban, industrial, natural/rural, and coastal. The goal is to provide a Toolbox for decision-makers and practitioners seeking effective and sustainable solutions to mitigate flash floods.

The deliverable is composed of four chapters. After the executive summary, Chapter 1 represents the introduction; Chapter 2 outlines the methodological approach; Chapter 3 summarizes key findings from the analysis and provides a critical discussion; Chapter 4 conclude the report.

The document is accompanied by five annexes. They followed an upside-down pyramid structure of analysis.

First, it started with a review of NBS initiatives in the European context of the last decade. Subsequently, the EU projects have been analysed. On these projects a focus on NBS for flood risk management has been carried out. For each NBS benefits and barriers have been highlited. Moreover, an analytical framework to assess the effectiveness of NBS has been developed.

The results were collected in annexes organised as follows:

- Annex I shows the results of the review of NBS initiatives. Initiatives such as the database, platforms, catalogues and guides developed within the framework of European projects over the last decade have been considered;
- Annex II shows a focus of existing NBS projects based primarily on the list of projects contained in the report "Nature-Based Solutions: State of the Art in EU-funded Projects" (2020);
- Annex III presents the outcome of the review regarding NBS to reduce flash flood and highlights benefits and barriers for implementation;
- Annex IV is related to the outcome of the NBS effectiveness analysis;
- Annex V represents the catalogue of NBS for each topographical area.

1. INTRODUCTION

1.1 DELIVERABLE OVERVIEW AND STRUCTURE

The aim of Activity 1.4 is to conduct a comprehensive review of current and ongoing NBS initiatives designed to mitigate the negative impacts of flash floods and reduce associated risks. This chapter illustrates how this deliverable was structured to achieve this objective. To this end, an analytical framework has been defined to assess the effectiveness of NBS project implementations, the primary benefits in terms of reducing flash flood risk, and the realization of various co-benefits, across different topographic areas such as urban, industrial, natural, and coastal. The analysis has been focused on identifying and examining the main obstacles hindering the implementation of NBS and undermining their effectiveness. These obstacles may include policy resistance, institutional constraints, conflicts, trade-offs between different benefits, and more. To finalize the analysis in order to assess the effectiveness of NBS, local and international experts have been interviewed. The Deliverable 1.4.1 was structured to show the methodological framework and the main results according to the Project statement (Table 1).

Table 1. Adherence of activities' goals of 1.4 and related deliverables' outputs

Deliverables running number: D.1.4.1. Catalogue of the Mitigation solutions available in the 4 different topographical areas		
Deliverable description: Catalogue of the Mitigation solutions available in the 4 different topographical areas (Urban areas, industrial areas, natural/rural areas, coastal areas)		
Activity	**Goals of the Activity 1.4**	**Respective actions described in the deliverable chapters**
Activity 1.4 Mitigation: Adapt, finetune and categorize existing NBS toolbox to mitigate the negative effects of flash flood events	Conduct a comprehensive review of existing and ongoing NBS initiatives designed to address the negative effects of flash floods	Chapter 2.1 Annex I Annex II
	Develop an analytical framework to assess the effectiveness of these NBS projects, their impacts on reducing flash flood risks, and the associated co-benefits. Identify and analyse the main barriers that hinder the implementation and effectiveness of NBS, such as policy resistance, institutional constraints, conflicts, and trade-offs. Utilize expert interviews to gather insights and finalize the analysis.	Chapter 2.2 Annex III Annex IV Annex V Chapter 3

2 METHODOLOGY

The methodology designed to create a catalogue of mitigation solutions for flood risk management in different topographical area (urban, industrial, natural/rural, and coastal areas) is structured into three main phases (Figure 1).

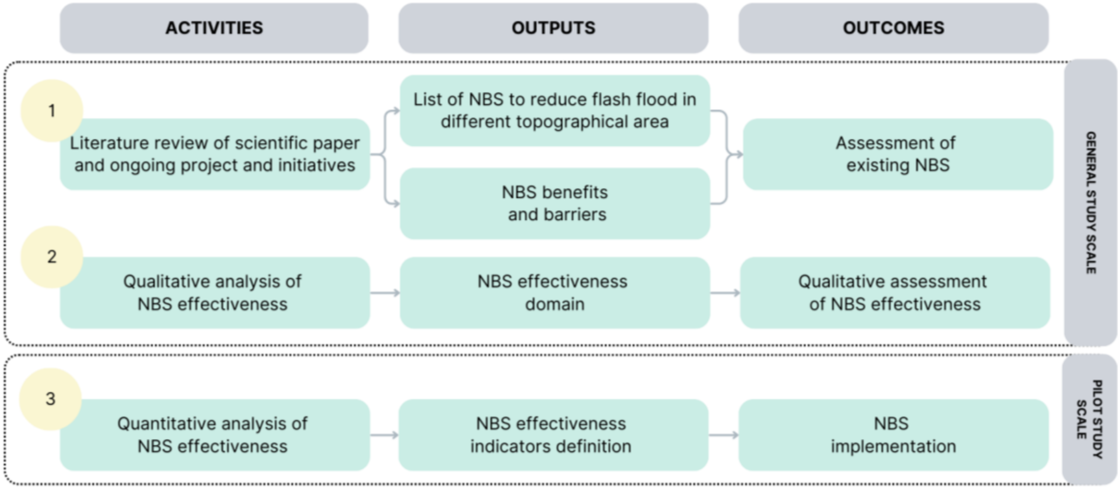

Figure 1. Methodological framework

During the **literature review phase**, the review of existing NBS project has been carried out. It begins with an overview of NBS initiatives in Europe over the past decade.

This phase has a dual purpose: on one hand, it aims to create a list of NBS to be classified for each of the four topographical areas; on the other, it seeks to highlight the benefits and barriers associated with each solution with the focus on flood risk mitigation. The goal of this phase is to provide a comprehensive assessment of both completed and ongoing NBS activities. This analysis allows for a better understanding of the range of solutions already implemented and the challenges faced, offering a foundation for identifying best practices and areas for improvement. Further details on this phase are elaborated in Chapter 2.1.

The second phase focuses on the **qualitative analysis of the effectiveness of NBS**. The effectiveness of NBS refers to the ability to achieve the intended objectives by effectively addressing environmental, social, and economic challenges (Ferreira et al., 2020). This can include aspects such as enhancing biodiversity, strengthening ecosystem services, mitigating climate change, reducing risks associated with catastrophic events (such as floods or urban heat islands), and promoting human well-being. The evaluation of NBS effectiveness is often based on criteria such as ecological sustainability, social inclusivity, cost efficiency, and resilience (Baceiro et al., 2020). Chapter 2.2 provides more details on this phase, explaining how these criteria are used to understand the added value of each NBS in terms of tangible outcomes.

The third phase deals with the **quantitative analysis of NBS**, which is typically conducted using specific indicators and measurable metrics. This quantitative analysis is crucial for the implementation phase of NBS and focuses on gathering concrete data to assess the impact of the solutions adopted (Kabisch N. et al., 2016).

Ultimately, while the qualitative analysis and literature review form the basis for the theoretical understanding of NBS, the quantitative analysis will become a focal point when transitioning to the practical implementation phase.

In this report, this phase has not been fully developed, since the quantitative assessment of NBS is linked to the activities of Co-design and promotion of NBS for the construction of the Participatory System Dynamic Model (Activity 2.4 "Lay the foundations for implementation of mitigating NBS through a participatory-based approach").

2.1 REVIEW OF EXISTING NBS INITIATIVES TO REDUCE FLASH FLOOD

The **literature review** was initially aimed at understanding the **existing NBS to reduce flash flood risks.** To this end, research was conducted through major academic channels such as Scopus and Google Scholar, using keywords like "Nature Based Solution," "Database NBS","Catalogue NBS," "Handbook NBS," "Guidelines NBS", "Flash Flood mitigation measures".

Among them, existing databases and platform of Oppla, ThinkNature NBS Explorer, EKLIPSE Mechanism, etc have been consulted. In each database, the search was refined by entering key words and context of analysis/main challenges. This analysis used "flood" as the keyword and "water management" as the field of application (Figure 2). Information was gathered on 40 European initiatives from 2015 to 2024 (Annex I).

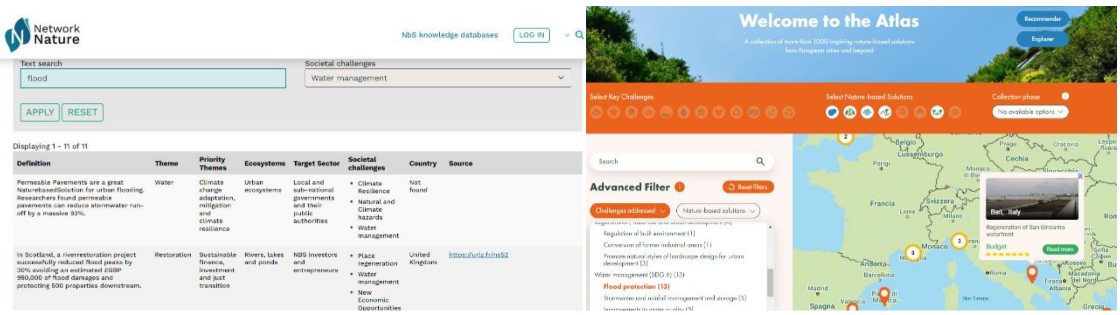

Figure 2. Some examples of NBS database

Given the large number of emerging initiatives and the extensive range of documents available online, this research effectively captures a broad and significant trend.

Subsequently, an **in-depth analysis of existing NBS projects** was carried out, based primarily on the list of projects contained in the report "Nature-Based Solutions: State of the Art in EU-funded Projects" (2020). The decision to focus the analysis on this document stemmed from its ability to highlight the main research projects from recent years, most of which have been completed, focusing on the adoption of NBS to address various challenges. This review was conducted by six independent experts in collaboration with European Commission staff and supported by the network of NBS projects funded by the Horizon 2020 program. Among the various sources available, this report was considered the most comprehensive, up-to-date, and well-structured in relation to NBS projects, enabling a more effective analysis for the implementation of solutions. Also, in this case, the focus of the analysis has been on the use of NBS for flash flood reduction.

Based on the list provided by the document, 34 European projects developed between 2015 and 2020 were analysed (Annex II). For each project, the main objective was examined, categorized as either NBS implementation or other goals, such as tool development, database creation, or guidelines. Subsequently, the projects were classified according to the functions performed by the NBS, such as heat island reduction, public well-being improvement, or flood mitigation.

Each project was also evaluated in relation to the NBS identified, promoted and implemented, classified across four topographical scales: urban, industrial, natural, and coastal.

Finally, NBSs collected by projects and others NBS deduced from the analysis of existing databases are shown in Annex III. For each NBS, a technical description was provided, along with the benefits and barriers highlighted. The benefits and barriers focus on the contribution NBSs provide in terms of flash flood reduction.

The benefits have been categorized into seven categories that include: the ability to absorb and store rainwater, reduce runoff, reduce flood and peak flow, recharge the aquifer, reduce coastal erosion, reduce pressure on water treatment systems, absorb energy related to water.

The barriers have been divided into eight macro-categories, including economic and financial constraints, stakeholder awareness and interest, technical challenges (such as limited space and lack of expertise), legal and regulatory restrictions, public acceptance, knowledge gaps (e.g., limited data), climate variability and climate change, and lack of coordination between sectors (including institutional and corporate involvement).

2.2 ANALYTICAL FRAMEWORK TO ASSESS NBS EFFECTIVENESS

The analytical framework for defining the effectiveness of NBS is based on the theoretical framework from the research of Sowińska-Świerkosz and Joan García (2021). They proposed a structured framework for evaluating the performance and effectiveness of NBS projects through a new approach that combines performance questions and tailored indicators to the specific objectives of NBS projects.

The decision to base the theoretical framework on this research lies in the fact that this method allows for more flexible and context-specific evaluations, while also incorporating qualitative issues that help define the problem.

In this work, the analytical framework used to assess the effectiveness of NBS refers to the qualitative evaluation and is summarized in Figure 3.

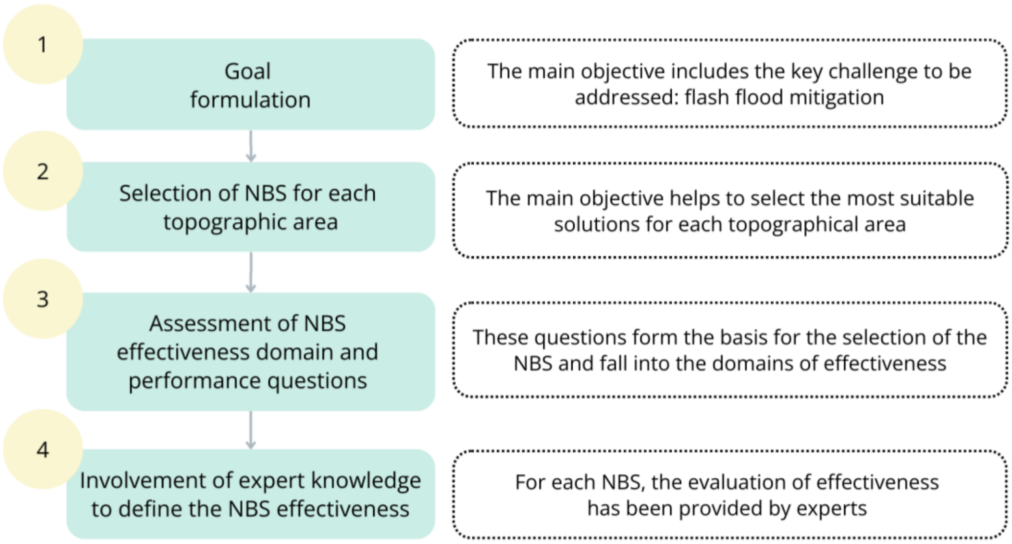

Figure 3. Analytical framework for the qualitative assessment of NBS effectiveness

The framework is based on four main phases:

i) Definition of the objective: Since the framework is theoretical and replicable, in this phase, the objective and actions to be undertaken are defined according to the specific study. In this case, the primary objective has been defined as the mitigation of flash floods.

ii) Definition of NBS for each topographical area: defining the main objective helps to select the solutions that best fit each topographical area. According to Sowińska-Świerkosz and Joan García (2021), factors influencing the selection of solutions include:

- Size and location: An urban forest is unsuitable for high-density residential areas;
- Available funds: Low-cost solutions are often chosen based on budget constraints;
- Time constraints: Urgent situations may require quicker, easier-to-install solutions;
- Local needs and traditions: Cultural preferences, such as a favouring of community gardens, can affect decision-making.

iii) Assessment of NBS effectiveness domain and performance questions: This phase begins with the development of targeted questions aimed at assessing the performance of NBS projects. These questions form the starting point for the analyst (based on the review conducted) to choose the appropriate solution and align with the key concepts regarding the effectiveness of NBS, as indicated by Sowińska-Świerkosz and Joan García (2021). In this work the performance domains and related questions are adapted to the specific issue of flash floods. Therefore, for each NBS categorized by topographical areas, the effectiveness domains and corresponding performance questions are shown in Table 2.

Table 2. Performance questions

Effectiveness domains	**Performance questions**
Flood risk reduction capability	Does NBS have the capacity to mitigate peak flows and surface runoff?
Policy capability	Can NBS be integrated into existing policy frameworks?
Management capability	Does NBS require low maintenance?
Social acceptance	Does NBS have the potential to create conflicts among different social groups?
Business plan/ Economic return	Is the NBS implementation supported by a business plan? ((Knowledge of the economic return on investment)
Performance in the long term	Does NBS offer long-term advantages?
Ease of implementation	Considering its designed topographic setting, is NBS technically straightforward to implement?
Adaptability to scale of intervention	Does NBS have the flexibility to be implemented in diverse topographic settings?
Co-benefits	Can NBS also produce co-benefits? Have they been identified?
Trade-offs	Can the NBS implementation lead to trade-offs? Have they been identified?

iv) Involvement of expert knowledge to define the NBS effectiveness: Each expert was asked to define an effectiveness rating scale for each domain. The rating scale consists of three levels of effectiveness: "low," "medium," and "high." The colour red indicates a low effectiveness domain, orange represents a medium-uncertain or context-dependent effectiveness domain, and green signifies a high effectiveness domain.

As a participatory approach and qualitative assessment, the threshold between low, medium and high is determined at the experts' discretion. Table 3 provides an example of effectiveness process evaluation.

Table 3. Example of evaluation of effectiveness

NBS	Effectiveness domain									
Green roofs/ walls/ vertical gardens	Flood risk reduction capability	Policy capability	Management capability	Social acceptance	Business Plan	Performance in long term	Ease of implementation	Adaptability to scale of intervention	Co- benefits	Trade off

Meetings were held with 8 experts in the scientific field. The decision to rely on this number of experts is based on two key reasons. First, individuals with significant expertise in NBS were interviewed. Additionally, the results from these experts were consistent. Given the observed uniformity, it was concluded that no further information was needed for the analysis.

Individual meetings with each expert took place between July and September 2024. The result for each NBS is to be considered an average of the individual results collected and is presented in Annex IV.

3. RESULTS AND DISCUSSION

3.1 NBS TO REDUCE FLASH FLOOD RISK

From the literature analysis, a set of NBS have been listed and classified for each topographical area as shown in the Table 4.

Table 4. Selected NBS to reduce flash flood for each topographical area

Nature Based Solution	Topographical area			
	Urban	Industrial	Natural	Coastal
Green roofs/ walls/ vertical gardens	x	x		
Rain gardens and bioswales (or vegetated swales)	x			
Permeable pavements/ green parking	x	x		
Urban wetlands and ponds	x			
Urban forest and trees	x		x	
River floodplains restoration- Channel Naturalization	x		x	

Riparian buffer zones - Bioengineering Techniques				
Pocket parks / natural playgrounds	x			
Urban Agriculture - Regenerative Agriculture	x		x	
Cycle and pedestrian green routes	x			
Rainwater Harvesting Systems	x	x		
Constructed Wetlands for Industrial Effluent		x		
Seagrass /flora restoration/ coastal permeable structures/ Natural Coastal Barriers			x	x
Sandy beach nourishment/ dune restoration and creation			x	x
Living Shorelines			x	x
Floodable Coastal Parks/Coastal wetlands/ Salt marshes				x
Natural inland wetland restoration	x	x		
Terraces and slope- Soil Conservation practices			x	
Green corridors			x	
Natural Water Retention Measures (NWRM): small dams, ponds, and retention basins, check Dams			x	
Sustainable Land Management techniques (agroforestry, rotational grazing, and conservation tillage)			x	
Afforestation and Reforestation			x	

For each NBS the main benefits and barriers have been analysed. The main benefit of NBS for flash flood reduction has been summarized as follows:

- Adsorb and store rainwater
- Reduce stormwater runoff
- Flood and peak flow reduction
- Recharge groundwater
- Enhance water infiltration
- Reduce coastal erosion
- Reduce pressures on urban surface water treatment systems

Each NBS can be capable of addressing one or more of these benefits (Figure 4). For example, green roofs, in both intensive and extensive forms, offer significant benefits for managing rainwater. **Intensive green roofs** can absorb 90-100% of precipitation, significantly delaying peak flows and capturing over 70% of rainfall. **Extensive green roofs**, depending on soil depth and the type of vegetation, can retain about 50% of runoff from small to moderate rain events (Czemiel Berndtsson, J., 2010; Hop & Hiemstra, 2012). **Rain gardens and bioswales** assist in managing stormwater by capturing runoff from streets and rooftops, slowing its flow, reducing peak flooding (Ishimatsu et al., 2017), and allowing dirt and pollutants to settle, which improves water absorption into the ground (Zölch et al., 2017).

Permeable pavements eliminate runoff by allowing water to infiltrate the underlying soil. These systems can manage not only the area they cover but also adjacent spaces, preventing surface water accumulation (Antunes et al., 2018). **Urban wetlands and ponds** are effective in reducing both runoff volume and peak flows, with the potential to reduce runoff by more than 80%, thus lightening the load on urban systems. However, their performance depends on sufficient storage capacity, as fully saturated wetlands can increase peak flow (Iwaszuk et al., 2019).

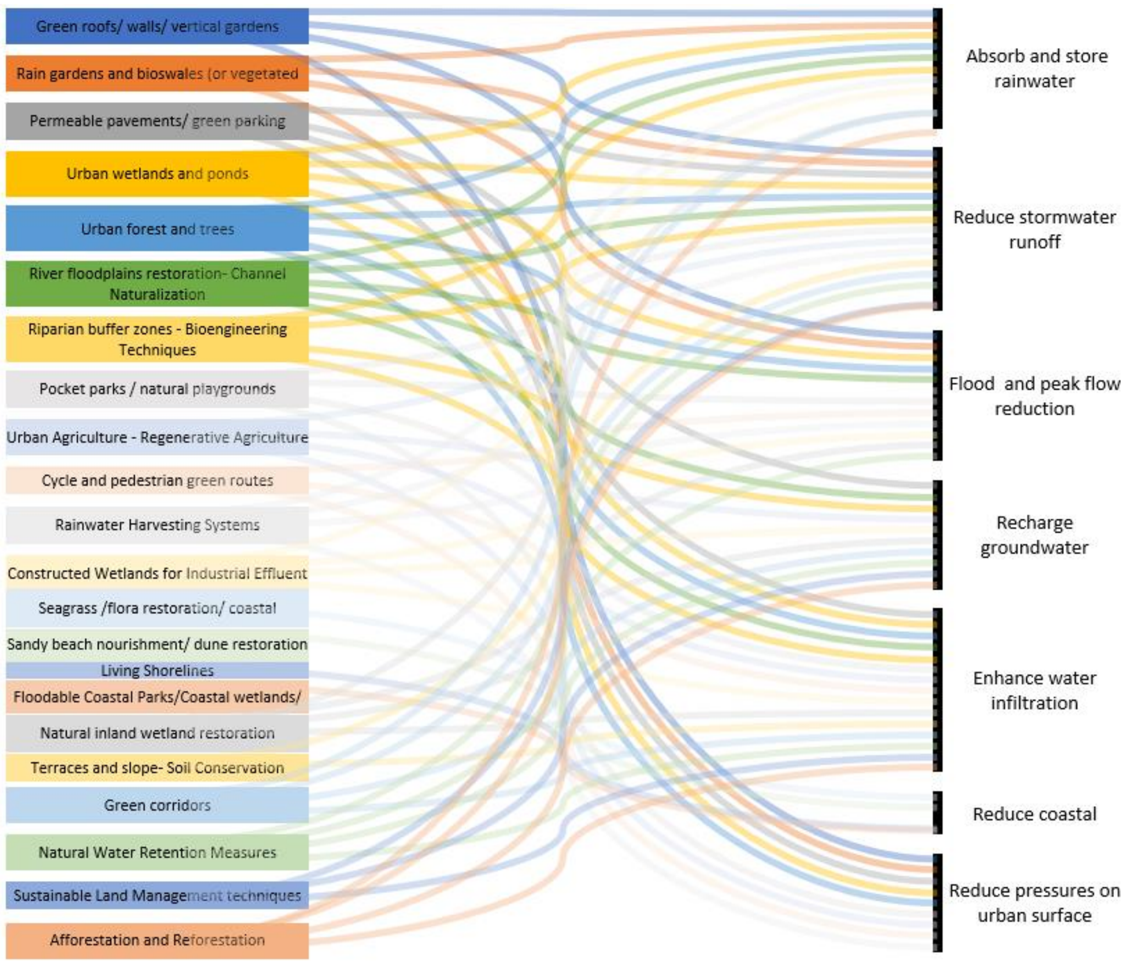

Figure 4. Main benefits of NBS to reduce flash flood

Urban forests and trees play a key role in managing rainfall, intercepting 10-15% of precipitation through their canopies. Tree roots improve infiltration, reducing surface runoff by up to 62% (Ozment et al., 2021).

Rainwater harvesting systems help reduce peak flow and overall runoff, potentially saving up to 24,000 liters of water annually from an average-sized roof, though further research is needed to assess long-term impacts (Freni & Liuzzo, 2019).

Pocket parks and public gardens, with their high infiltration rates, almost entirely eliminate surface runoff, making them excellent for reducing flood risks. Similarly, community gardens enhance infiltration and improve groundwater recharge, contributing to low-flow conditions (Gehrels et al., 2016).

With reference to coastal areas, **Natural Water Retention Measures (NWRM)**, such as small dams, ponds, retention basins, check dams, and coastal ecosystems like wetlands, floodable parks, and salt marshes, are highly effective in reducing the risk of flash floods, particularly in coastal areas. These systems function by slowing down the movement of water, allowing it to be stored temporarily and gradually released. This delay reduces the intensity and speed of floodwaters, helping to mitigate the sudden surges typical of flash floods. Coastal wetlands and salt marshes act as natural barriers, absorbing excess stormwater and dissipating wave energy before it reaches more vulnerable inland areas. Additionally, check dams and retention basins increase the water's infiltration into the ground, which helps manage runoff during heavy rains. Floodable coastal parks also provide intentional low-lying spaces where floodwaters can be diverted, lowering the risk to surrounding urban regions. Together, these natural infrastructures not only reduce the impact of flash floods but also enhance long-term climate resilience by improving water management and protecting coastal ecosystems (European Commission, 2014; Narayan et al. 2016).

Similarly, implementation barriers were also assessed for each NBS. The main barriers of NBS implementation for flash flood reduction has been summarized as follows:

- Economic and financial constraints
- Stakeholders' awareness and interest
- Technical challenges (limitated space, lack of expertise)
- Legal and policy restrinctions
- Public acceptance
- Knowldege gap (limited data)
- Coordination between sector (institutional- companies involvement)

Most NBSs share economic, technical and coordination obstacles between institutional levels (Figure 5).

According to Korniyenko (2021), one of the primary barriers to implementing green roofs is the high initial installation cost, which can deter widespread adoption. Moreover, green roofs require complex maintenance and present design limitations, especially when integrating them with existing buildings. Technological challenges, such as optimizing green roofs for stormwater management and addressing structural issues, also complicate their implementation. Additionally, the lack of cohesive political support and economic incentives hinders broader usage, particularly in regions where local governments fail to provide adequate incentives or guidelines.

Rain gardens face similar barriers, including financial constraints, inadequate long-term maintenance plans, and fragmented governance structures that complicate collaboration among various stakeholders. There is often a lack of community engagement and understanding of the benefits of green infrastructure like rain gardens, limiting their potential to effectively manage stormwater and improve urban resilience (Chaffin et al. 2016).

Stefanakis (2019) identifies key barriers to the effective implementation of urban wetlands and ponds. A major challenge is the difficulty of integrating such natural systems into densely built urban environments. Urban wetlands and ponds often face competition for space due to urban development pressures, making it challenging to allocate sufficient land for their construction and maintenance. Social and governance barriers also exist, such as public unawareness of the benefits of these systems and insufficient collaboration between stakeholders, including policymakers, engineers, and environmental planners.

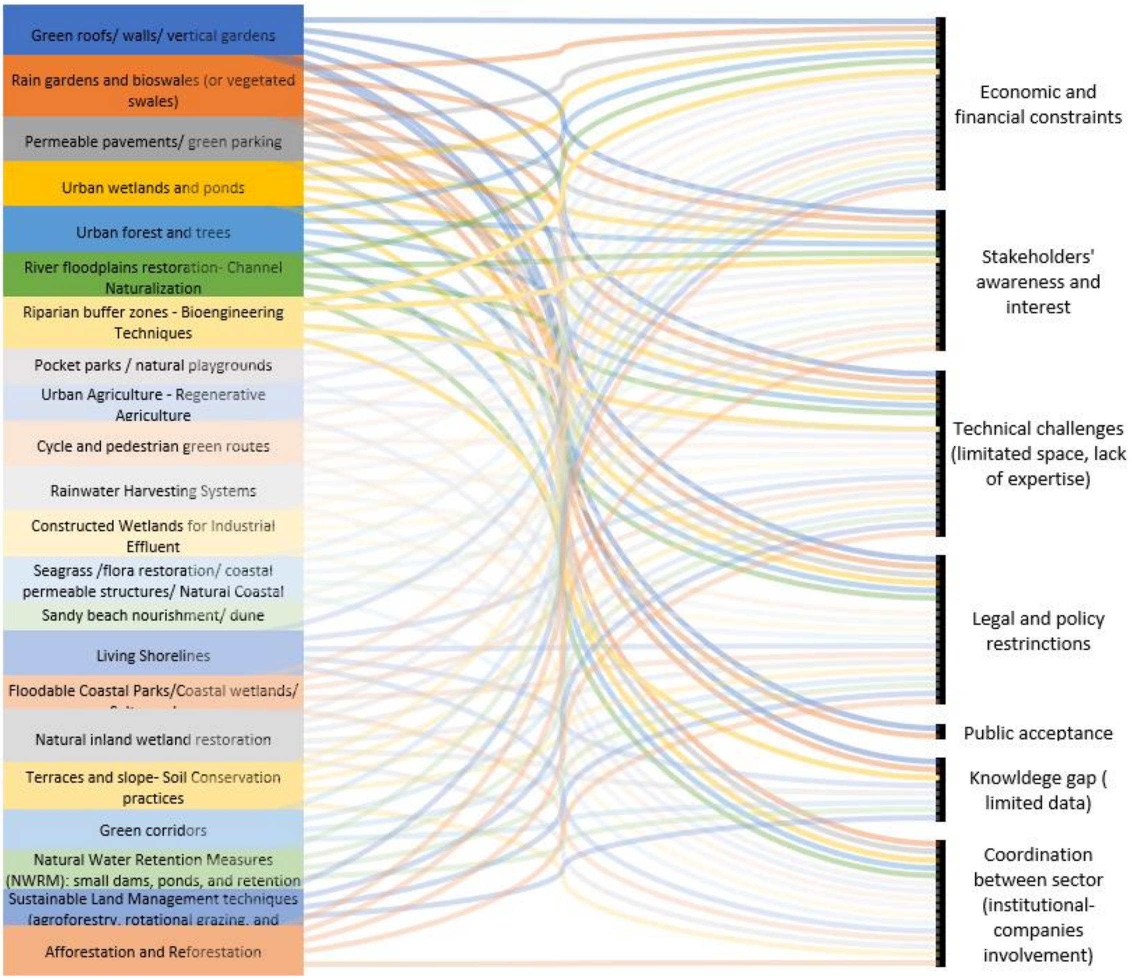

Figure 5. Main barriers to reduce flash flood

Technical challenges, particularly regarding maintaining water quality and preventing pollutant accumulation from surrounding urban areas, are also significant. Long-term maintenance requirements, such as managing vegetation and sediment buildup, can be costly and labor-intensive, making these systems less appealing to urban planners seeking low-maintenance solutions. Lastly, regulatory and financial constraints limit the wider adoption of constructed wetlands in cities, as inadequate funding and regulatory frameworks fail to fully support nature-based urban water management solutions.

For more details, refer to Annex III.

3.2 EU NBS PROJECTS ANALYSIS OUTCOMES

The analyses conducted between EU projects have highlighted some critical issues that deserve particular attention. One of the main concerns is the **lack of a specific focus on flash flood risk**. As shown in Figure 6, none of the projects examined directly address flash flood risk in a targeted way. Although ten of the projects aim to use NBS to reduce flood risk, including flash floods, this approach remains quite general and unspecific. Most of the projects implement and promote NBS with the primary goal of addressing other challenges, such as improving urban liveability or mitigating heat waves, with only indirect benefits in terms of reducing runoff and peak flows. These findings emphasize **the need to develop more targeted strategies, specifically focusing on flash flood management, to ensure an effective mitigation of this growing risk**.

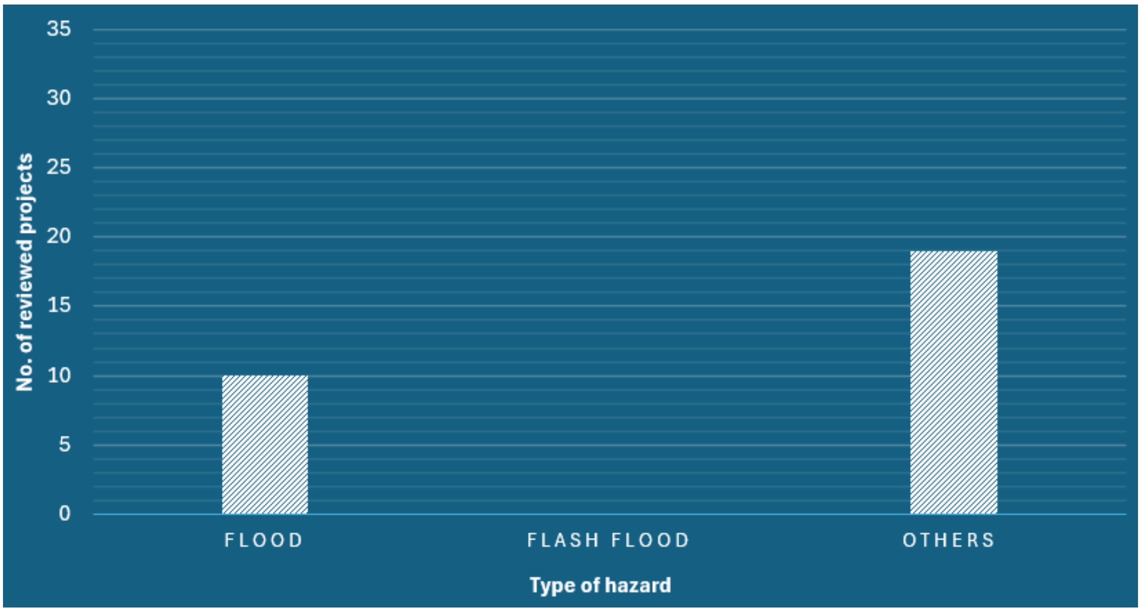

Figure 6. Nº. of reviewed projects addressing flood and flash-flood management

Another aspect that requires further attention is the application of NBS across different topographical areas. As shown in Figure 6, the majority of NBS studies are concentrated in urban and natural areas, where these solutions have been more extensively explored.

However, when it comes to industrial and coastal areas, there is a noticeable gap in both research and practical application. **To fully harness the benefits of NBS, it is crucial to expand the scope of study and experimentation in industrial and coastal zones**, ensuring that these regions are not overlooked in future sustainability efforts. Developing tailored NBS for these areas could offer significant opportunities for innovation in environmental management and resilience building.

Building on the previous considerations, it becomes evident that the most employed NBS projects are those focused on urban and natural scales (Figure 7). Specifically, of the 35 projects examined, 23 projects refer to the urban topographic scale, while 18, to the natural topographic scale.

In urban environments, solutions such as urban forests, reforestation, the creation of green roofs, and green walls are frequently used to enhance liveability, reduce heat waves, and manage stormwater. In natural areas, reforestation and landscape restoration are often prioritized to support ecosystem services and biodiversity.

When it comes to industrial areas, however, the focus shifts toward more specific interventions. The construction of artificial wetlands and the restoration of floodplains are favoured in these regions to manage industrial runoff and improve water quality. These solutions not only help mitigate environmental impact but also provide added resilience against flooding and other hydrological risks.

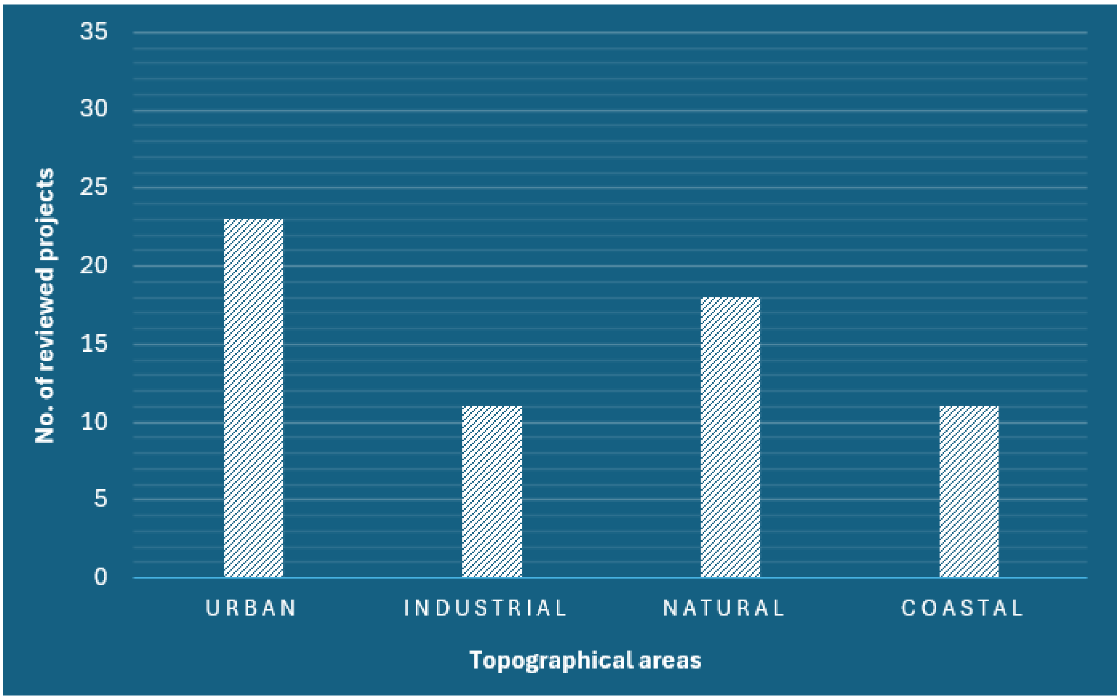

Figure 7. Nº. of reviewed projects addressing different topographical areas

In coastal zones, the emphasis is on restoring coastal wetlands, marshes, and dunes. These NBS are particularly effective in buffering against coastal erosion, managing storm surges, and protecting biodiversity. By reinforcing natural coastal defences, these solutions help reduce vulnerability to rising sea levels and extreme weather events, while also supporting the health of coastal ecosystems. **Expanding the implementation of NBS in industrial and coastal areas remains a key opportunity for future projects to address a wider range of environmental challenges.**

Figure 8 illustrates the frequency of NBS promoted/implemented derived from the analysis of the EU projects, for each topographic area.

Regarding to **natural topographical area**, wetland restoration is a NBS used in projects such as NAIAD and AQUACROSS. The MOORLIFE project has also used wetland restoration to reduce downstream flood risks. This NBS has also been applied in agricultural regions where wetlands have historically been drained. Projects such as OPTWET focus on wetland restoration in these areas to improve water filtration and nutrient retention, address agricultural runoff, and improve water quality.

In the Naiad Project, riparian buffer zones contribute to the natural management of flood risk and improve the resilience of water systems through ecosystem restoration. The ASTI project investigates the effectiveness of riparian buffer zones in controlling floodwaters and reducing downstream flood events or GROW GREEN - Implements riparian buffer zones as part of urban green infrastructure to improve water management and flood resilience.

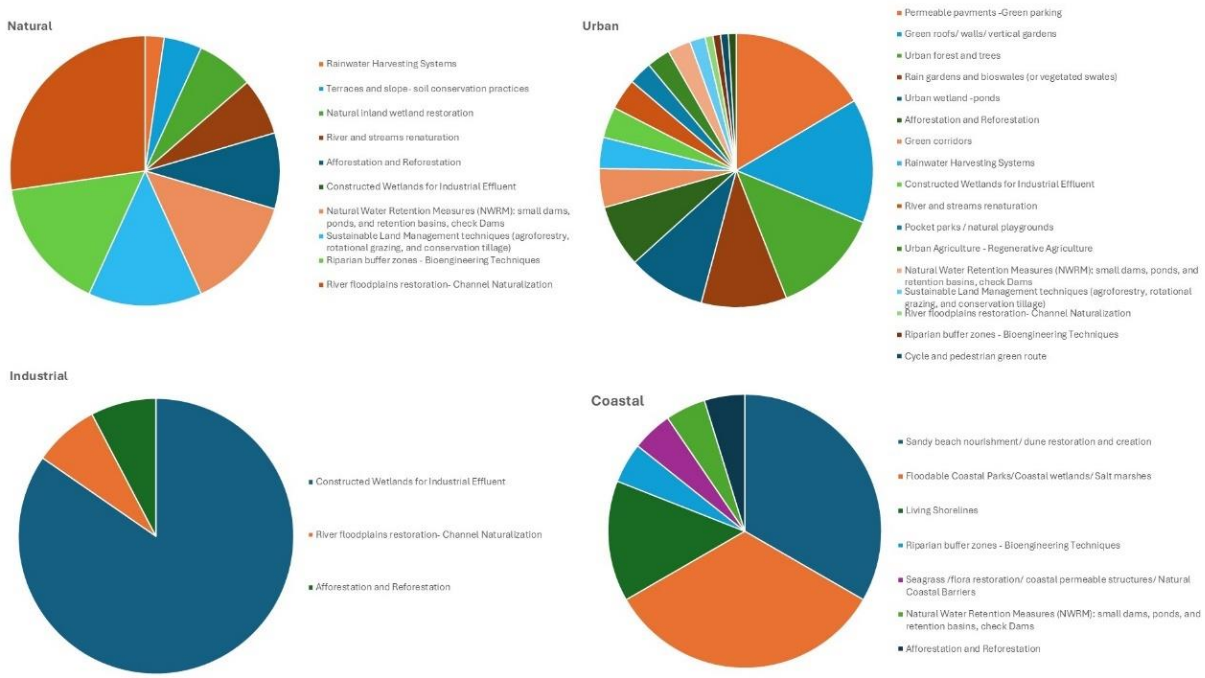

Figure 8. Frequency of suggested- implemented NBS solutions from project analysis for each topographical area

In **urban topographical areas**, the NBS most promoted by projects are permeable pavements. For example, CLEVER CITIES incorporates permeable paving in urban design to enhance stormwater management and reduce flooding. GROW GREEN implements permeable paving as part of green infrastructure to improve urban resilience and manage runoff. INTERLACE focuses on integrating permeable surfaces in urban areas to enhance water infiltration and decrease surface runoff. NATURE4CITIESadvocates for the use of permeable pavements as a strategy for sustainable urban drainage and enhancing green spaces. NATURVATION highlights the role of permeable pavements in urban areas for managing rainwater and mitigating urban heat. REEN4GREYexplores the potential of permeable pavements as a transition from grey to green infrastructure for effective stormwater management.

The use of urban forests is also strongly promoted. The REEN4GREY project studies the potential of urban forests and agriculture to transform urban environments and effectively manage stormwater. NATURVATION explores the benefits of urban forests and farming in enhancing urban ecosystems and mitigating the effects of climate change. Similarly, the AQUANES project focuses on integrating urban green spaces, including forests and urban agriculture, to improve urban water management and biodiversity.

In relation to **industrial topographical areas**, the most prominently promoted Nature-Based Solution (NBS) is constructed wetlands. For example, NATURVATION examines the role of constructed wetlands in managing stormwater and reducing flood risks in urban and industrial landscapes. ASTI investigates, among other objectives, the effectiveness of constructed wetlands for flood management and stormwater control in industrial contexts. Similarly, OPTWET explores constructed wetlands as effective solutions for flood management and stormwater treatment in industrial settings.

With reference to the **coastal topographic area**, the BLUEHEALTH project examines the benefits of coastal wetlands and dune restoration in improving resilience to floods and storm surges. The MARS project also investigates the integration of coastal wetlands and dune systems for flood risk reduction and habitat enhancement. The MOORLIFE project, although primarily focused on peatlands, explores coastal restoration efforts, including dune systems, for ecosystem resilience and flood management. NATURE4CITIES as well as NATURAVATION, promotes the use of coastal wetlands and dune restoration as strategies for managing urban flood risk and improving coastal resilience.

For more details, refer to Annex II.

3.3 NBS EFFECTIVENESS ANALYSIS OUTCOMES

Table 5 provides an evaluation of effectiveness of NBS across different domain according to expert knowledge. For more details, refer to Annex IV.

The result of the effectiveness analysis conducted by the knowledge is consistent with what is reported in the literature, as explained below:

Green roofs, walls, and vertical gardens are increasingly being used as a tool for sustainable urban development due to their environmental benefits. For this reason, the domain regarding the effectiveness of producing co-benefits is high. Research highlights their ability to reduce rainwater runoff, manage stormwater, and mitigate urban heat island effects (Berardi et al., 2014; Mentens et al., 2006). This ability depends on the type of green roof (extensive or intensive) and therefore the effectiveness in relation to flood reduction assumes a medium value.

Table 5. Results of effectiveness analysis with expert knowledge

Nature Based Solutions	Domain of effectiveness: Flash Flood risk reduction capability	Policy capability	Management capability	Social acceptance	Business plan- economic return	Performance in the long term	Ease of implementation	Adaptability to scale of intervention	Co-benefits	Trade-offs
Green roofs/ walls/ vertical gardens										
Rain gardens and bioswales (or vegetated swales)										
Permeable pavements -Green parking										
Urban wetland -ponds										
Urban forest and trees										
River floodplains restoration- Channel Naturalization										
Riparian buffer zones - Bioengineering Techniques										
Pocket parks / natural playgrounds										
Urban Agriculture - Regenerative Agriculture										
Cycle and pedestrian green route										
Rainwater Harvesting Systems										
Constructed Wetlands for Industrial Effluent										
Seagrass /flora restoration/ coastal permeable structures/ Natural Coastal Barriers										
Sandy beach nourishment/ dune restoration and creation										
Living Shorelines										
Floodable Coastal Parks/Coastal wetlands/ Salt marshes										
Natural inland wetland restoration										
Terraces and slope- soil conservation practices										
Green corridors										
Natural Water Retention Measures (NWRM): small dams, ponds, and retention basins, check Dams										
Sustainable Land Management techniques (agroforestry, rotational grazing, and conservation tillage)										
Afforestation and Reforestation										

Similarly, rain gardens and bioswales (vegetated swales) are effective bioretention systems for managing stormwater. Studies by Hunt et al. (2006) and Davis et al. (2009) confirm that these systems can improve water quality and hydrological performance, making them crucial in urban water management. The effectiveness domain related to flood risk reduction takes on a high value.

Permeable pavements, sometimes referred to as green parking solutions, provide another valuable approach for managing urban runoff. Collins et al. (2008) and Ferguson (2005) suggest that permeable pavements not only reduce runoff but also help recharge groundwater, offering a viable alternative to traditional impermeable surfaces like asphalt .

Urban wetlands, including constructed ponds, serve as multifunctional systems that contribute to stormwater management while supporting biodiversity. According to Mitsch and Gosselink (2015) and Tiner (2016), these wetlands play a key role in flood control, nutrient cycling, and habitat creation, making them valuable in urban settings. Furthermore, urban forests and trees contribute to ecosystem services by improving air quality, reducing energy use, and managing stormwater. Research by Nowak and Dwyer (2007) and McPherson et al. (2005) demonstrates the significant environmental and economic benefits that urban forestry can provide to cities.

The restoration of river floodplains and the naturalization of channels are also crucial for flood mitigation and ecosystem health. Studies by Palmer et al. (2014) and Wohl et al. (2015) show that these techniques improve riverine systems by enhancing biodiversity, reducing flood risks, and restoring natural sediment regimes. Similarly, riparian buffer zones and bioengineering techniques, as explored by Lowrance et al. (1984) and Shields and Nunnally (1984), offer natural solutions for protecting waterways from pollution and stabilizing streambanks.

Small green spaces, such as pocket parks and natural playgrounds, provide essential recreational opportunities in densely populated urban areas while contributing to environmental sustainability. Marcus & Francis (1997) and Guitart et al. (2012) emphasize the role of these small parks in promoting social interaction and urban green space accessibility. Urban agriculture, including regenerative practices, complements these initiatives by fostering local food production, enhancing food security, and contributing to sustainable land use, as discussed by Altieri & Nicholls (2012) and Lovell (2010).

Cycle and pedestrian green routes are gaining recognition as key elements of sustainable urban mobility. These pathways promote active transportation modes like walking and cycling, as highlighted by Litman (2016) and Pucher & Buehler (2010), leading to healthier and more sustainable cities. In addition, rainwater harvesting systems are increasingly integrated into urban designs to reduce pressure on freshwater supplies and manage stormwater. Research by Khare and Varun (2011) and Campisano et al. (2013) shows how these systems can improve water conservation and resilience in urban environments.

For more industrial contexts, constructed wetlands offer an effective solution for treating effluents. Vymazal (2011) and Kadlec & Wallace (2009) demonstrate the efficiency of constructed wetlands in treating wastewater from various industrial sources, contributing to cleaner water and healthier ecosystems. In coastal areas, seagrass restoration and the use of permeable structures are important for maintaining coastal resilience. Orth et al. (2006) and Shepard et al. (2011) highlight the role of seagrass ecosystems in protecting coastlines from erosion and enhancing marine biodiversity.

Beach nourishment and dune restoration are crucial strategies for combating coastal erosion. According to Hanson et al. (2002), these techniques provide both protective and recreational benefits by restoring the natural landscape of coastal areas. Furthermore, the implementation of living shorelines, as discussed by Sutton-Grier et al. (2015), offers a hybrid approach to coastal defense that combines natural and engineered elements, enhancing resilience to sea-level rise.

Floodable coastal parks and salt marshes are also effective for managing coastal flooding and providing habitat for wildlife. Gedan et al. (2011) emphasize the protective role of salt marshes, which buffer storm surges and rising tides while also supporting coastal ecosystems. Inland wetland restoration plays a similar role in mitigating flooding and improving water quality in non-coastal areas. Research by Mitsch & Day (2006) shows the importance of these wetlands in regulating water flows and restoring ecological balance.

Terracing and soil conservation practices, as discussed by Lal (2001), are vital for preventing soil erosion and maintaining productive landscapes, especially in agricultural regions. Green corridors, which connect fragmented habitats, contribute to biodiversity conservation and landscape connectivity. Bennett & Mulongoy (2006) provide a comprehensive review of how green corridors can be integrated into ecological networks, enhancing the resilience of both natural and urban environments.

Finally, natural water retention measures, such as the ones described in the European Commission's (2014) policy document, are essential for managing water resources sustainably. These measures reduce flood risks by slowing water runoff and promoting natural infiltration. Sustainable land management techniques, as described by Pretty (2008), play a critical role in maintaining soil health, enhancing ecosystem services, and supporting long-term agricultural productivity.

All the result of the analyses conducted is summarised in the catalogue of NBS (Annex V).

4. CONCLUSION

This deliverable, part of Activity 1.4, provides a comprehensive catalogue of NBS to reduce flash floods tailored for four key topographic areas: urban, industrial, natural/rural and coastal. Its aim is to provide decision makers and practitioners with effective and sustainable solutions to mitigate flash floods.

The construction of the catalogue and the analysis of the effectiveness of the NBS designed for the four topographic areas involved a methodological process divided into three main phases: literature review, creation of the analytical framework for effectiveness assessment and assessment of the qualitative effectiveness of NBS through expert knowledge.

From the above analysis and reflections, several conclusions can be drawn regarding the use of NBS in different topographic contexts for flood risk reduction.

First, it is evident that most of the examined projects focus on urban and natural areas. This reflects a trend towards using NBS to improve urban liveability, mitigate the negative effects of heat islands and manage flood events without specifying the exact causes or nature of the event. Similarly, in natural areas, NBS are widely adopted to promote biodiversity and improve ecosystem services. This highlights that urban resilience and the protection of natural ecosystems are key priorities in the research projects analysed. Secondly, less attention is given to industrial and coastal areas, where NBS could play an equally crucial role. In industrial areas, solutions such as the construction of artificial wetlands and the restoration of floodplains could offer significant opportunities to improve water management and reduce environmental impacts. In coastal areas, targeted solutions such as the restoration of wetlands, salt marshes and dunes are particularly effective in combating coastal erosion and mitigating sea level rise.

Another critical aspect is the lack of specific attention to the risk of flash floods. Although some projects address flood risks in general, none of them specifically target flash floods, which are a growing threat, especially in densely urbanized areas. This highlights the need for further research and targeted interventions to use NBS specifically to address flash flood risks.

The qualitative evaluation process of the effectiveness of NBS highlighted that the most effective solutions for flash flood risk reduction are those that also offer ecological and social co-benefits, but require significant investments and strong political support for their large-scale implementation. Policies need to balance effectiveness, costs and co-benefits to ensure the adaptability of these solutions to different territorial contexts. The participatory approach for qualitative evaluation allowed for the collection of additional information, such as the scale of implementation. Experts have emphasize that is easier to implement some solutions on a small scale rather than on a large scale. Solutions like green roofs, rain gardens, and permeable pavements are relatively easy to apply in localized or limited urban contexts. However, when attempting to expand these solutions on a large scale, challenges related to costs, management complexity, and adaptability to different territorial contexts and policy emerge. On the other hand, solutions that are more effective on a large scale, such as reforestation, wetland restoration, or river renaturalization, require extensive spaces and significant resources, as well as longer implementation times and coordination between multiple actors. These factors make large-scale implementation more complex than localized projects.

The catalogue contributes to the scientific debate on flood risk management by providing an evidence-based framework to assess the effectiveness of NBS with a specific focus on flash floods. The activities presented here are qualitative in nature but serve as a basis for the activities to be developed in other tasks. Indeed, the quantitative analysis for the assessment of effectiveness will be carried out through the activities planned in Task 2.4 and aimed at building a Participatory Dynamic Model (PSDM). In this context and in line with the project objectives, this document serves as a valuable resource for decision makers for a preliminary assessment of NBS aimed at flash flood reduction in different topographical settings, helping to guide flood risk management strategies in a more targeted way. It also lays the foundations for a participatory and constructed process able to increase cooperation at multiple levels thanks to the development of the PSDM model.

Annex I: Review of NBS initiatives

Annex II: Review of existing NBS EU projects

Annex III: NBS benefits and barriers

Annex IV: NBS effectiveness analysis

Annex V: Catalogue of NBS

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