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Barriers and enablers for the implementation of large-scale Nature-based Solutions for flood mitigation in the Po Valley, Italy

Chiara Zenaro

Student number: 1276441

Supervisor: Anna Duden

Second reader: Pita Verweij

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Abstract

Nature-based Solutions (NBS) represent holistic, cost-effective approaches that address complex challenges while yielding multiple co-benefits, thereby being an alternative to or complementing traditional "grey" solutions. Large-scale NBS have proven effective in mitigating floods, particularly in flood-prone countries like the Netherlands (NL). Moreover, these measures not only provide long-term flood mitigation but also enhance habitat, ecosystems, and human well-being. However, in the Po Valley (PV), a crucial socio-economic area in Northern Italy susceptible to catastrophic floods, large-scale implementation and research on NBS for flood mitigation are still lacking. The PV relies on an extensive embankment system to manage floods, but this method is considered insufficient to meet the future challenges posed by climate change, land use, and urbanization, which are projected to increase the frequency of catastrophic floods. Given the similarities between the NL and the PV in terms of landscape, socio-economic development, and flood-related challenges, a comparative analysis of the ex-ante and ex-post barriers and enablers to large-scale NBS uptake between these regions could provide lessons for the PV to promote NBS implementation to enhance flood protection. A mixed-method approach based on both qualitative and quantitative research was adopted, including literature reviews, spatial modelling, and interviews with experts. First, the impacts and causes of floods in the PV were examined to provide background information on the magnitude of the issue. Second, ex-ante and ex-post barriers and enablers to NBS adoption in the PV and the NL respectively were investigated. Then, the comparison between barriers and enablers allowed for the identification of lessons for the PV to take up from the NL experience. Lastly, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted to highlight potential opportunities and threats associated with NBS implementation or non-implementation in the PV.

In general, findings reveal that the PV faces more and greater barriers than the NL, while enablers are often hindered by short-term and small-scale actions. Lessons from the NL thus highlight the importance of long-term, integrated, and participative strategies for policymakers and stakeholders to foster large-scale NBS implementation for flood mitigation in the PV. By doing so, the PV can address future flood-related challenges by providing large-scale and long-term flood protection and achieving co-benefits deriving from NBS implementation.

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1. Introduction

Nature-based solutions (NBS) are gaining momentum worldwide as strategies to tackle current and future global societal challenges related to climate change. NBS are defined as solutions that are inspired by and use nature to solve complex issues and provide co-benefits at the environmental, social and economic levels, therefore answering the call for sustainable strategies for multiple-scale challenges (*Press Corner*, n.d.). One of the challenges where NBS have proven to be effective is flood risk mitigation, i.e. reducing the likelihood of floods occurring and the associated impacts (Thaler et al., 2023). Climate change is projected to increase the frequency and magnitude of floods, placing societies at a higher risk of catastrophic flood damage (Arnell & Gosling, 2016; Merz et al., 2021). Generally, catastrophic floods are generated from unexpected and unusual heavy and/or prolonged rainfall or unpredictable failure of flood defence (e.g. embarkments), leading to a high level of damage (Arnell & Gosling, 2016; Merz et al., 2021). In this context, NBS can be implemented to achieve long-term objectives for flood mitigation (Hartmann et al., 2018; Raška et al. 2022; Ruangpan et al., 2020). Large-scale implementation of NBS, i.e. catchment level, can provide flood mitigation in vast areas by reducing flood peak, and rural areas offer suitable space for large-scale NBS adoption, unlike urban settings where space is limited (Hartmann et al., 2018; Hooijer et al., 2004). By combining different NBS such as floodplain and river restoration, retention basins, afforestation, and riparian vegetated buffers, it is possible to increase the water storage capacity of rivers, water infiltration in the soil, and decrease run-off and peak discharge, thus providing flood risk reduction (Raška et al. 2022; Ruangpan et al., 2020). Besides, large-scale NBS uptake provides multiple co-benefits such as habitat and biodiversity restoration and creation of recreational areas, thus fostering environmental, societal and economic benefits (Cohen-Shacham et al. 2016; Debele et al. 2019). For these reasons, research generally claims that NBS for flood mitigation are more cost-effective, adaptive, and beneficial to the environment than traditional "grey" infrastructure, e.g. dikes and embankments, and have been increasingly implemented in several countries (Mubeen et al., 2021; Raška et al. 2022; Ritzema & Van Loon-Steensma, 2018; Sahani et al., 2019).

A region highly threatened by catastrophic flood events, that could benefit from the implementation of large-scale NBS, is the Po Valley (PV), in Northern Italy. The PV is the most extended lowland in Italy and is pivotal for the national economy as it hosts intensive agricultural and industrial activities, providing 50% of the national GDP (Musolino et al., 2017; Romano & Zullo, 2016). It is crossed by the longest Italian river, the Po, which supports several purposes such as hydroelectric production, navigation, and irrigation (Musolino et al., 2017; Pedro-Monzonís et al., 2016; Romano & Zullo, 2016). The PV, which heavily depends on the river for its prosperity, has been historically suffering from catastrophic floods, which in the past have caused hundreds of lives to be lost and billions of damages (Romano & Zullo, 2016). The Po River is prone to large flow fluctuation with frequent floodings and low-flow periods (Pedro-Monzonís et al., 2016). Moreover, this situation is projected to worsen in the near future, increasing flood vulnerability in the PV, driven by climate change, land-use change, and urbanization sprawl (García-Valdecasas Ojeda et al., 2022; Pedro-Monzonís et al., 2016; Romano & Zullo, 2016). The main flood protection measures adopted in the PV are levee systems and embarkment heightening that confine water overflow in specific areas (Castellarin et al., 2010; Curran et al., 2020). Paradoxically, several studies claim that these measures have been increasing flood vulnerability and consequently flood risk over the past years, due to levee failure and the so-called 'levee effect' (Castellarin et al., 2010; Domeneghetti et al., 2015; Zanchettin et al., 2008). According to this principle, levee systems reduce the perceived risk of regular flooding, thus encouraging the development of urban settlements in flood-prone areas that are still at risk of sporadic but catastrophic events. Hence, this phenomenon increases the vulnerability for low-frequency but high-impact flood events and highlights the need for new flood mitigation strategies such as NBS (Castellarin et al., 2010; Coppola et al., 2014; Dankers & Feyen, 2008; Zanchettin et al., 2008). Nevertheless, in the PV, the utilization of NBS remains limited and restricted to small-scale applications (Cardinali et al., 2013; Liquete et al., 2016; Otto et al., 2016).

As opposed to the PV, which still lacks large-scale NBS implementation to reduce flood risk, the Netherlands (NL) is at the forefront of using large-scale implementation of NBS to protect against flooding (Zevenbergen et al. 2015). The NL is similar to the PV in terms of landscape, rapid historical socio-economic development, land-use and flooding issues, and like the PV, it used to rely mainly on dikes and embarkments to mitigate floods (Curtis & Campopiano, 2014). However, two catastrophic floods in 1993 and 1995 led to a radical change of direction in flood management, resulting in the development and implementation of one of the best-known and most successful examples of large-scale NBS implementation for flood mitigation, called the 'Room for the River' project (RftR) (Ritzema & Van Loon-Steensma, 2018). From 2006, this project led to the implementation of thirty-nine NBS across the country and extensive restoration of the riverine system and its ecosystem, allowing for more room for the rivers Rhine and Meuse (de Vriend et al., 2015; Ritzema & Van Loon-Steensma, 2018). Through the realization of the RftR, the NL successfully reduced the Rhine flood peak discharge by 1000 m^3s^{-1}, meeting the desired target for flood protection, and at the same time restoring habitat and biodiversity along the river system (Sokolewicz et al.,2011; Zevenbergen et al. 2015).

Research indicates that the successful uptake of NBS highly depends on the presence of barriers and enablers that can hinder or favour the implementation of NBS (Kumar et al., 2020; Raška et al., 2022; S. Sarabi et al., 2020; S. E. Sarabi et al., 2019). Barriers to the implementation of NBS can derive for instance from political settings, uncertainty due to their technical implementation and effectiveness, low social acceptance and mistrust, lack of incentives and availability of land, or land-ownership issues (Raška et al., 2022; S. E. Sarabi et al., 2019). On the other hand, enablers can be activated to overcome these barriers and lead to the implementation of NBS (Kumar et al., 2020; Ramírez-Agudelo et al., 2020; S. E. Sarabi et al., 2019). When evaluating the feasibility of NBS implementation it is therefore essential to acknowledge the barriers and enablers that may effect their uptake.

Comparing the different approaches for flood mitigation of PV and the NL, it can be noted that despite the similarity of contexts there is a gap in the implementation of large-scale NBS for flood mitigation in the PV. Moreover, there is no prior study that extensively researched the potential for NBS implementation for flood mitigation in the PV up to now. This leaves room for investigation on ex-ante barriers and enablers that are hampering or could foster NBS implementation to mitigate flood in the PV. Lessons derived from ex-post barriers and enablers involved in the implementation of best practices, such as the RftR case in the NL, can guide the implementation of NBS for flood mitigation at a large scale in the PV, also due to the similarity of the two contexts, therefore making the comparison between the PV and the NL relevant. Eventually, from the comparison of ex-ante and ex-post barriers and enablers in the PV and the NL respectively, recommendations to policy makers can be provided, to inform on key factors needed to foster large-scale NBS implementation to mitigate flood in the PV. This contributes to filling the gap in knowledge on the potential feasibility of large-scale NBS to tackle flood risk in one of the most flood-prone yet vital socio-economic areas of Italy.

1.1. Research aim

This exploratory research aims to provide recommendations to policy makers on key enabling factors to foster large-scale implementation of NBS as an alternative or complementary strategy for flood mitigation in the PV, which up to now mainly consists of dikes and embankments. Given the scarcity of scientific research on the topic in the PV, and the fact that NBS adoption is significantly conditioned by barriers and enablers, a comparison of ex-ante barriers and enabling factors to NBS implementation in the PV and ex-post barriers and enablers occurred in best practices in the NL is relevant to fill the aforementioned knowledge gap, and is justified by the similarity of the two contexts, in terms of landscape, historical socio-economic development, land use, and vulnerability to flooding. To fulfil the aim of this research, the following research question (RQ) and sub-research questions (SQs) are formulated:

RQ: *What lessons can the PV learn from the NL on the implementation of large-scale NBS for flood mitigation?*

- **SQ1:** *Which regions in the PV are affected by floods, in which ways, and what are the underlying causes?*
- **SQ2:** *What is the state of the art of NBS for flood mitigation in the PV and what are ex-ante barriers and enablers for large-scale implementation?*
- **SQ3:** *What is the state of the art of NBS for flood mitigation in the NL and what are ex-post barriers and enablers for large-scale implementation?*
- **SQ4:** *What lessons can be derived from the comparison of ex-ante and ex-post barriers and enablers in the PV and in the NL respectively?*

2. Theoretical background

2.1. Nature-Based Solutions

The term NBS was coined in the late 2000s' by the International Union for the Conservation of Nature (IUCN), to define strategies that aim to tackle societal challenges by creating co-benefits for both society and nature (Eggermont et al., 2015). IUCN defined NBS as

"*Actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (*Nature-based Solutions*, n.d.)

The term NBS, though broad in definition and scope, can be considered as an umbrella expression that groups more familiar concepts such as, but not limited to, ecosystem-based adaptation, green and blue infrastructures, ecological engineering and ecosystem services (Bridges et al., 2021; Eggermont et al., 2015; Eisenberg & Polcher, 2019). NBS implementation requires a holistic inter- and transdisciplinary approach to deliver ecological, environmental and socioeconomic benefits, thus NBS are action-oriented, multifunctional, cost-effective, multiscale and context-specific, and advocate participatory processes among different stakeholders to promote the co-design, co-creation and co-management of interventions (Eisenberg & Polcher, 2019; Kumar et al., 2020; Pauliet et al., 2017). NBS can thus provide effective adaptation and mitigation measures to counteract several issues arising from climate change (Cohen-Shacham et al., 2016).

2.1.1. NBS for flood mitigation

NBS can be adopted as large-scale mitigation measures for the management of hydro-meteorological events such as floods, being an alternative or additional measure to traditional "grey infrastructures", i.e. dikes and levee systems (Sahani et al., 2019). In general, NBS for flood mitigation include strategies that allow for more room for the water, promote water retention upstream and increase water infiltration in the soil to decrease flood peak and reduce water run-off (Castellarin et al., 2010; Hooijer et al., 2004; Pramono, 2021). Examples of common large-scale interventions are, among others:

- the restoration of floodplains by the removal and reallocation of banks more inland, so to allow water to overflow in specific areas, and floodplain lowering to increase storage capacity (Hooijer et al., 2004; Raška et al., 2022);
- the restoration of rivers and the creation or re-opening of secondary channels to reestablish natural deposition/erosion processes, to improve flow dynamics and increase drainage by giving more room to the river (Hooijer et al., 2004; Sahani et al., 2019; Raška et al., 2022);
- the creation of retention basins and ponds to increase storage capacity upstream (Hooijer et al., 2004; Raška et al., 2022);
- afforestation and riparian buffer strips, which besides being essential to support the ecological functions of river systems, act as flood control measures by stabilizing banks and regulating the surface flow and run-off (Hooijer et al., 2004; Ireland & Power, 2022, Sahani et al., 2019).

2.1.2. Barriers to NBS implementation

The implementation of NBS can be hindered by several factors that become barriers to the uptake of NBS. Raška et al. (2022) identified that the most frequently encountered barriers are a lack of institutional framework and political will to uptake NBS, uncertainty and limitations regarding the effectiveness of NBS in achieving the desired results, lack of funding, and land ownership issues. S. E. Sarabi et al., (2019), detected institutional fragmentation, inadequate regulations, uncertainty on technical implementation of NBS implementation, and limited availability of land and time for the implementation as additional barriers to NBS uptake. Additionally, according to S. Sarabi et al., (2020), barriers may also derive from a lack of social awareness and support, risk aversion and resistance to change. To integrate the knowledge from different sources on barriers to NBS adoption, and simplify their explanation in this research, barriers are divided into the following five categories:

1) *Political barriers (P)*

Political barriers entail a lack of political willingness and lacking or fragmented institutional and regulatory framework that can hamper the uptake of NBS (Raška et al., 2022; S. E. Sarabi et al., 2019). A lack of sense of urgency among policymakers and short-term commitments and vision can also affect the implementation of NBS as these usually require a long time to produce benefits, thus generating a discrepancy between short-planning and long-term goals (S. Sarabi et al., 2020). Another political barrier is the lack of an integrated multi-scale and multi-disciplinary approach to flood management (S. E. Sarabi et al., 2019). Also, a lack of cooperation among stakeholders can compromise the implementation of NBS as it can negatively influence stakeholders' perception of NBS cost, benefits and effectiveness (Ramírez-Agudelo et al., 2020).

2) *Uncertainty-related barriers (U)*

NBS implementation is hampered by the uncertainty of their effectiveness in achieving objectives, as NBS usually provide benefits in the long term (S. E. Sarabi et al., 2019). Moreover, as NBS require a comprehensive approach involving a high degree of complexity, they trigger several uncertainties related to technical and technological capacity (Ramírez-Agudelo et al., 2020). Thus the absence of standards and guidelines for NBS implementation can create a gap between conceptual knowledge and operational knowledge, which may lead to favour grey solutions over NBS (Kumar et al., 2020; S. E. Sarabi et al., 2019; Wickenberg et al., 2021).

3) *Social barriers (S)*

A lack of social awareness and acceptance can hinder the uptake of NBS (Kumar et al., 2020; Ramírez-Agudelo et al., 2020). This factor depends above all on the social dynamics that determine sociocultural values, beliefs, traditions and behaviour, and thus concur in shaping the perception of NBS (Ramírez-Agudelo et al., 2020). Low levels of awareness and acceptance can generate mistrust and aversion to change, thereby leading local communities to prefer grey solutions over NBS and oppose NBS implementation (S. Sarabi et al., 2020).

4) *Economic barriers (E)*

Lack of or limited financial resources can hinder the uptake of NBS (Raška et al., 2022; S. E. Sarabi et al., 2019). At the same time, short-term funding can limit the realization of NBS as they may require a long time to be established, thus exceeding the availability of the funds (S. E. Sarabi et al., 2019).

5) *Spatial barriers (SP)*

Usually, NBS require more land than grey infrastructures (S. E. Sarabi et al., 2019). Thus spatial barriers mostly refer to spatial constraints in terms of land availability and land ownership. Especially in the case of large-scale NBS implementation, private land-owners lose their land as it is allocated to implement flood mitigation strategy. This usually generates opposition from landowners and residents (Raška et al., 2022; S. Sarabi et al., 2020).

Among these barriers, Kumar et al. (2020) identified political and uncertainty-related barriers are the most critical to the implementation of NBS. Furthermore, a study by S. Sarabi et al. (2020) ranked barriers to NBS implementation according to their perceived importance, i.e. their power to hamper NBS implementation, resulting in the political barriers being perceived as the most important, followed by uncertainty-related barriers, social barriers, economic barriers and lastly spatial barriers. Besides, the research assessed that barriers are linked to each other and are interdependent (Raška et al., 2022; S. E. Sarabi et al., 2019). For instance, political barriers can drive uncertainty, social and economic barriers, as they strongly depend on and are influenced by the political framework (Kumar et al., 2020; Raška et al., 2022). For instance, a lack of supportive regulations for NBS adoption can prevent stakeholders from collaborating and committing to the implementation of NBS, causing in return fewer investments in NBS and less social acceptance (Kumar et al., 2020; Raška et al., 2022). Similarly, uncertainty-related barriers can generate mistrust in NBS, thus triggering social barriers (S. Sarabi et al., 2020). Then social barriers can prevent investments and create opposition around land expropriation due to low social acceptance and aversion to change, thus triggering economic and spatial barriers (S. Sarabi et al., 2020). Lastly, lack of funding can hinder the activation of compensation schemes, thereby leading to spatial barriers, and can enhance low acceptance of NBS, thus also fostering social barriers (S. Sarabi et al., 2020). S. Sarabi et al., (2020) assessed that while political, uncertainty-related and social barriers are the most influential hindering barriers to NBS uptake, economic and spatial barriers have the least hindering power on NBS uptake, being strongly conditioned by the other barriers (S. E. Sarabi et al., 2019).

2.1.3. Enablers for NBS implementation

Several enablers can overcome barriers and promote NBS implementation. The enabling factors presented below summarize findings from the literature and, to highlight their connection to related barriers, are grouped according to the same five categories.

1) *Political enablers (P)*

A clear and shared vision among political actors and other stakeholders is key in enabling NBS uptake as it creates a shared understanding of the issues to be tackled and opens the dialogue on possible solutions (S. E. Sarabi et al., 2019; Thaler et al., 2023). Integrated regulations among different institutional actors and multi-scale decision-making processes are fundamental for the successful actuation of NBS, as they link supra-national regulations from the national to the municipal level, thereby supporting the implementation of NBS across different scales (Kumar et al., 2020; Ramírez-Agudelo et al., 2020; S. E. Sarabi et al., 2019). At the same time, national and regional regulations facilitate NBS implementation by creating adequate institutional contexts that encourage their operationalization (S. E. Sarabi et al., 2019). A partnership between stakeholders from different sectors (e.g. scientists, policy-makers, citizens, etc.) and multiple scales (global, national/regional and local levels) enables the implementation of NBS by ensuring the achievement of multiple benefits (Kumar et al., 2020; Ramírez-Agudelo et al., 2020; S. E. Sarabi et al., 2019). Among the stakeholders, meso-scale actors from the municipality, and micro-scale actors, such as citizens, landowners and NGOs, are the most influential in determining the uptake of NBS, as they provide the necessary institutional framework, land and financial support for the development of NBS (S. E. Sarabi et al., 2019); while transboundary actors are crucial to encouraging the mainstreaming of NBS concepts and creating networks around NBS (S. E. Sarabi et al., 2019).

2) Uncertainty-related enablers (U)

The measurement of NBS effectiveness through standardized methods and the establishment of monitoring programs that can provide evidence of NBS benefits, enable filling the gap between conceptual and technical knowledge on NBS and help to develop guidelines for the operationalization of NBS projects (Kumar et al., 2020; S. E. Sarabi et al., 2019). Experimentation and co-creation of knowledge provide another way to overcome knowledge-related barriers and can be effective strategies to decrease uncertainties related to the implantation of NBS projects (S. E. Sarabi et al., 2019; Wickenberg et al., 2021). Moreover, education, training programs, and knowledge-sharing among experts can generate learning opportunities to foster best practices and activate long-term capacity building. This can counteract the lack of knowledge and guidelines that hampers the implementation of NBS (Kumar et al., 2020; S. E. Sarabi et al., 2019). Also, apart from tackling uncertainty-related barriers, experimentation, co-creation of solutions and education broaden acceptance and appreciation of NBS, thus acting as social enablers (S. E. Sarabi et al., 2019).

3) Social enablers (S)

Participatory processes should be fostered to reach a shared understanding of the challenges and a common formulation of problems to tackle with NBS (Wickenberg et al., 2021). Through long-term collaboration, stakeholders can take part in the co-planning and co-design of solutions to generate co-benefits. This fosters social learning and widens the acceptance of and awareness of NBS (Kumar et al., 2020; S. E. Sarabi et al., 2019). By considering the values and needs of different participants, trust can be built and a larger support to NBS implementation can be achieved (Kumar et al., 2020).

4) Economic enablers (E)

In general, the financing of NBS mainly derives from both the public and the private sector. The former group entails funding provided by local, regional, and national governments or international organizations (e.g. research funding from the European Union), whereas the latter group mainly refers to foundations, NGOs and private corporations (Ramírez-Agudelo et al., 2020). The use of economic instruments and incentives can encourage the uptake of NBS in different ways, for instance, price-based instruments can promote a more sustainable use of the ecosystems, quantity instruments can limit those activities that are detrimental to nature, while grants can encourage the adoption of NBS over grey solutions. These measures can be fostered to promote stakeholders' investments in NBS projects (S. E. Sarabi et al., 2019).

5) Spatial enablers (SP)

Issues can arise from a lack of compensation schemes for landowners, thus hampering land acquisition for the implementation of NBS. Adequate compensation mechanisms support the implementation of NBS implementation by decreasing resistance from locals (i.e. residents and farmers) who have to give in to their land property or may be affected by temporarily reduced productivity due to the measure implemented (i.e. retention areas) (Raška et al., 2022; Thaler et al. 2023). Moreover, social enablers can play a role as spatial enablers (S. E. Sarabi et al., 2019). In this case, the increased awareness and acceptance of NBS can for instance prevent clashes on land use, thus enabling land expropriation to make room for NBS interventions (S. E. Sarabi et al., 2019).

2.2. Barriers - Enablers Framework

The barriers and enablers discussed are grouped and summarized in a barriers-enablers framework, depicted in Figure 1. Barriers are ordered according to their importance as reported by S. Sarabi et al. (2020), thus the higher the barrier the more it has the power to hinder NBS implementation. Barriers are connected by arrows to indicate the interdependency between them. For each barrier group, are the enablers that can contribute to overcoming those barriers.

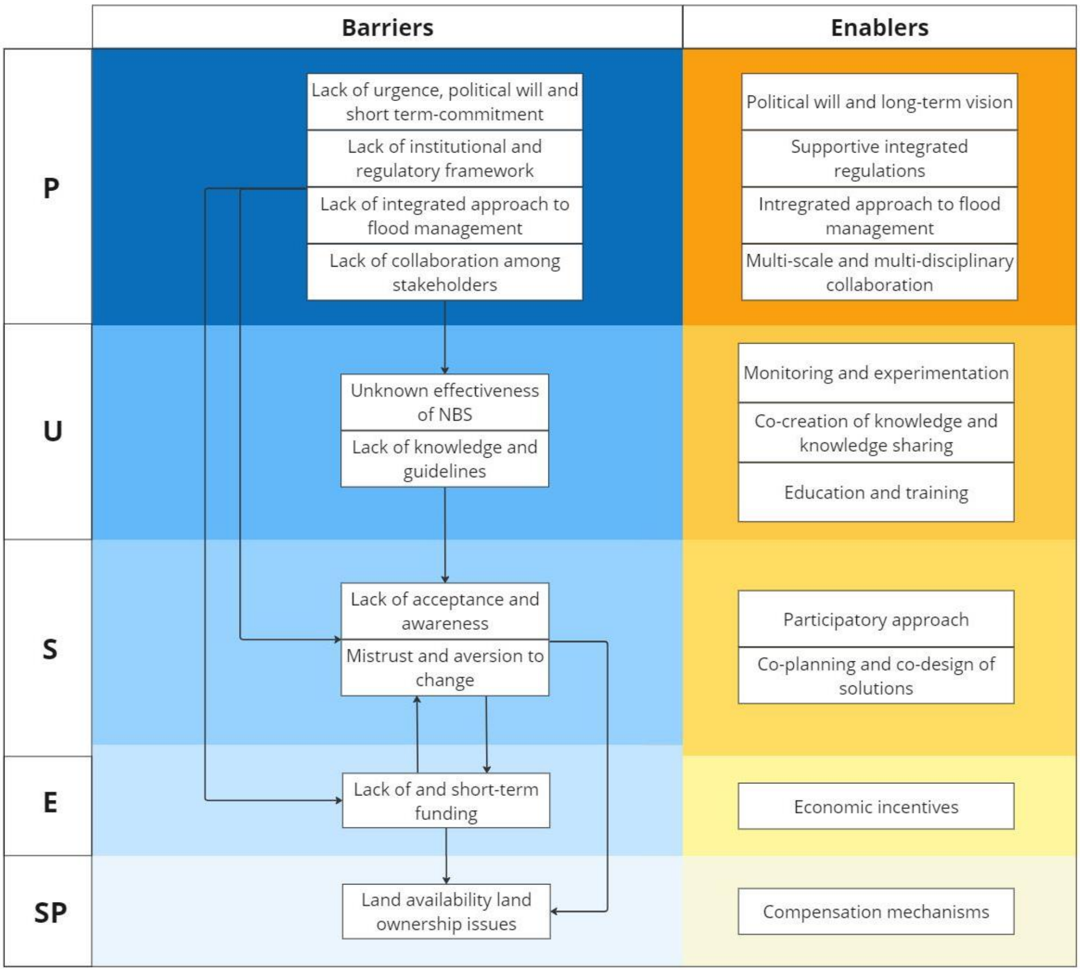

Figure 1 Barriers-enablers framework for NBS implementation. Barriers and enablers refer to the political (P), uncertainty-related (U), social (S), economic (E) and spatial (SP) categories. Barriers are ordered according to their importance in

hampering NBS implementation the most hampering is on top, and the least hampering at the bottom. Arrows show the interdependency among barriers.

2.3. Study area

This section briefly describes both the PV and the NL in terms of landscape, historical socioeconomic development and land use, flood history and mitigation strategies adopted, and briefly compares the two regions to highlight why lessons learned in the NL can foster the implementation of NBS for flood mitigation in the PV.

2.3.1. The Po Valley

The area of research is the PV, an alluvial plain that extends for nearly 47,800 km^2 in Northern Italy and spans across five regions: Piemonte, Lombardia, Emilia-Romagna, Veneto and Friuli-Venezia Giulia (Romano & Zullo, 2016). The PV is crossed by the Po River, the longest Italian river, which originates in the Western Alps and flows eastward for 652 km through Piemonte, Lombardia, Emilia-Romagna and Veneto, finally draining in the Adriatic Sea, as depicted in Figure 2 (Domeneghetti et al., 2015; Musolino et al., 2017; Romano & Zullo, 2016). Some areas are subject to subsidence, especially the central and eastern regions of the PV (Carminati & Martinelli, 2002).

The rapid development of the PV during the 20th century led to the conversion of land into agricultural, industrial and urban settings, making the PV a strategic area for the Italian economy (Domeneghetti et al., 2015; Musolino et al., 2017; Pedro-Monzonís et al., 2016; Romano & Zullo, 2016). The PV is the foremost agricultural and industrial area of the country contributing by 35% to the national agricultural production, by 55% to the national livestock production, by 29% to the industrial production and by 50% to the national GDP (Musolino et al., 2017). Furthermore, it hosts big and medium-sized urban centres, and with 361 inhabitants/km^2 is one of the most densely populated areas in Italy (Romano & Zullo, 2016).

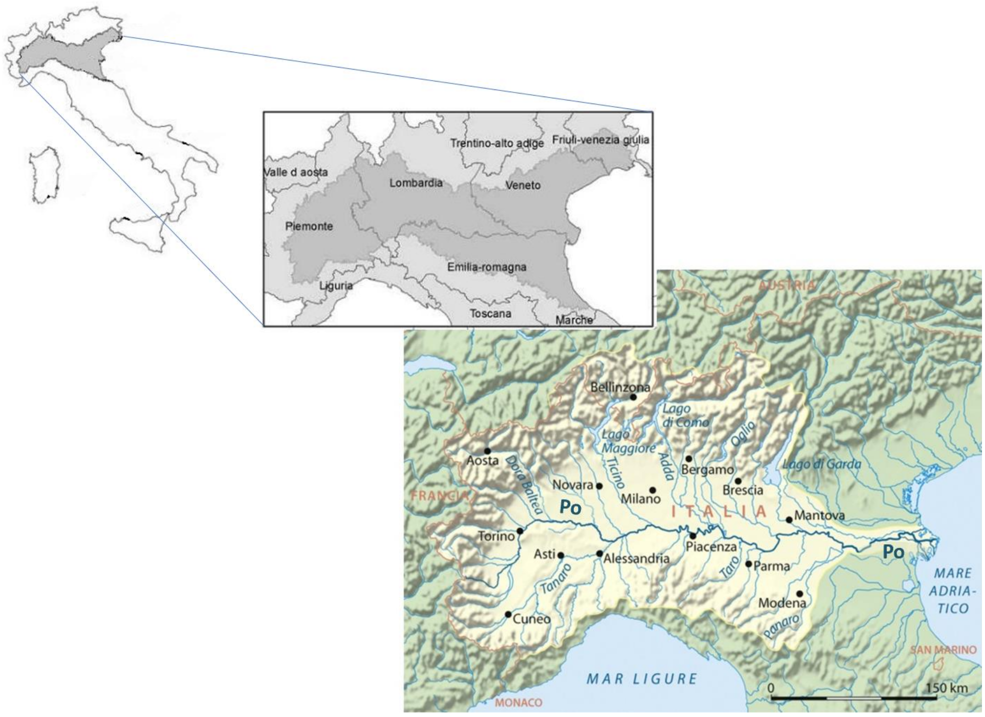

Figure 2 The left image shows the geographical location of the PV in Italy. The central image shows the five regions that are part of the PV and the extent of the PV in each region (dark grey area). The right image highlights the Po river and its tributaries. Image adapted from Romano & Zullo (2016).

The rapid development of the PV however, led to the proliferation of settings in flood-prone areas thus increasing flood exposure (Romano & Zullo, 2016). The PV is highly vulnerable to flooding and prone to catastrophic flood events that in the past caused major economic damages and life losses (Curran et al., 2020). Eighteen major floods occurred between 1705 and 1951, mostly due to embankment failures (Domeneghetti et al., 2015). The catastrophic inundation of the Polesine region in 1951, which claimed 100 lives, displaced 200,000 people and damaged 900 houses, became a benchmark for the development of an extensive flood protection system based on the reinforcement and construction of new embarkments, which eventually reached more than 2,900 km of extension to protect the PV from medium-frequency flood events (i.e. flood with a return time of 200 years), (Domeneghetti et al., 2015; Masoero et al., 2013). Since the 60s' the levee system has been continuously strengthened and risen, being the main strategy adopted against flooding (Curran et al., 2020; Domeneghetti et al., 2015; Romano & Zullo, 2016).

2.3.2. The Netherlands

The NL is a flat area home to the Rhine and Rhine Delta, which flows for 170 km across the country before draining into the North Sea, and the Meuse, as shown in Figure 3 (Silva et al., 2004). The NL has a complex hydrology, 25% of the country is below the average sea level and a large part of the country is affected by subsidence (van Stokkom et al., 2005).

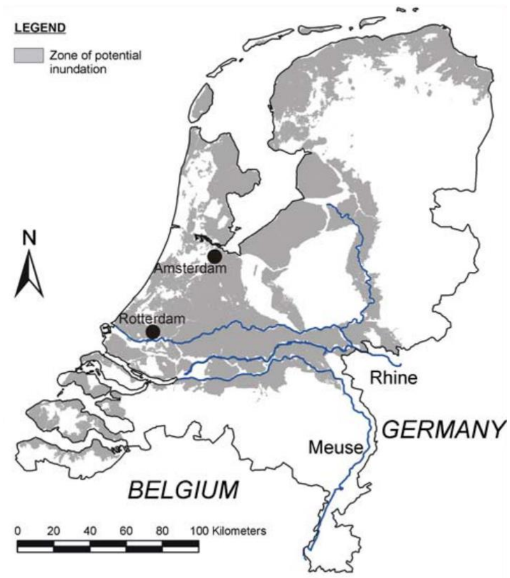

Figure 3 The NL and the Rhine river. Areas of potential inundation are highlighted in grey. Image retrieved from De Moel et al. (2011).

Over the last centuries, the country experienced intensive development thanks to an extensive regulatory system of water bodies and the adoption of a system of dikes and levees for flood mitigation that led to rapid socioeconomic growth and land use change (De Moel et al., 2011; van Stokkom et al., 2005). However, this also led to intensified urbanization of flood-prone areas, such as the delta region, causing an exponential increase in potential flood disasters (De Moel et al., 2011). Catastrophic flood events occurred in 1953, 1993, 1995, and 1998 due to the higher water discharge rate of the rivers Rhine and Meuse (Ritzema & Van Loon-Steensma, 2018; Silva et al., 2004; van Stokkom et al., 2005). The flood in 1993 reached a peak discharge of 3,120 m3/s leading to extensive flooding in the southern regions of the NL, causing 17,000 hectares to flood, damaging 5580 private houses, and causing a 100 million euros loss (Kok et al., 2002; Wind et al., 1999). In 1995 the peak discharge reached 2,861 m3/s causing over 15,500 hectars to flood, the evacuation of 250,000 people and 1 million livestock, and overall damages of 80 million euros (Kok et al., 2002; Ritzema et al., 2017; Stokkom et al. 2009; Wind et al., 1999). The flood in 1998 caused losses of 500 million euros (Kok et al., 2002).

Even though Oukes et al. (2022) claim that the NL faces institutional, social and spatial challenges when it comes to flood management, e.g. lack of political and social support due to a low sense of urgency and lack of risk awareness, difficult coordination between stakeholders, lack of space and highly anthropic environment, these catastrophic events triggered the urge to uptake new strategies to tackle flood risk, especially in anticipation of future challenges posed by climate change, such as rainfall intensification and higher river discharge (Ritzema & Van Loon-Steensma, 2018; Silva et al., 2004; Van Herk et al., 2015; van Stokkom et al., 2005). The government realized that traditional flood mitigation strategies based on the concept of "fighting with water" were no longer sufficient to face the increasing flood risk in the NL, and a new approach of "living with water" was needed, allowing the river more room (Oukes et al., 2022; Van Herk et al., 2015). This shift in paradigm led to the transition from the traditional flood protection strategies, which mainly entailed the construction of dikes, to an integrated flood risk management and the introduction of a multi-layer safety concept in the Dutch National Water Plan (Oukes et al., 2022; Zevenbergen et al., 2015). New policies were thus introduced which no longer encompassed quick discharge of water to mitigate flood but favoured an integrated management based on water retention, storage and discharge (Ritzema & Van Loon-Steensma, 2018). This led the Dutch government to launch the 'Room for the River' project in 2006, to restore the storage capacity of the floodplain and enhance ecological processes along the river Rhine and Meuse (de Vriend et al., 2015; Ritzema & Van Loon-Steensma, 2018). This intervention, which is considered to be one of the most successful cases of large-scale NBS implementation, aimed to reach flood protection and promote the ecological functions of the river system by creating more room for the river (Zevenbergen et al. 2015). Interventions mostly occurred in rural areas and included solutions such as floodplain lowering and restoration, river restoration, creation and reconnection of side channels, and creation of water retention areas (van Stokkom et al., 2005; Zevenbergen et al. 2015). These interventions allowed to increase the discharge capacity of the river Rhine by 1,000 m^3s^{-1} thus providing reduced flood peak, and achieved other co-benefits such as the establishment of areas for recreation, habitat and biodiversity (Ritzema & Van Loon-Steensma, 2018; Ruangpan et al., 2020; Stokkom et al., 2005; Straatsma et al., 2019). The approach to this project was innovative and several enabling factors concurred to overcome the above-mentioned barriers (Ritzema & Van Loon-Steensma, 2018). According to Rijke et al. (2012), the success of the RftR programme lies in fact in its vision, policy framework, economic justification, regulation and compliance, leadership, capacity building, public engagement and research.

2.3.3.Comparing the Po Valley and the Netherlands

The PV and the NL show similarities in terms of socio-economic development and land-use and differences in their approach to flood mitigation strategies. Both regions are flat plain areas home to extensive river networks and delta, with some areas affected by subsidence and already below sea level. Also, they both experienced rapid economic growth in the past decades, which led to rapid land-use change, wide-spread urbanization and a severe anthropization of the territory. This led to increased flood risk and the occurrence of catastrophic floods in both the PV and the NL, which reacted by enhancing and strengthening embarkments and dikes. However, although the PV and the NL share similar contexts and flood-related challenges, the change in paradigm occurred in the NL after the floods in 1993 and 1995 opened the way to the large-scale implementation of NBS and validated the effectiveness of this strategy to reduce flood (Ruangpan et al., 2020). The PV instead, and more in general Italy, still relies on traditional flood mitigation strategies, namely embarkments and dikes (Curran et al., 2020; Romano & Zullo, 2016).

Although the implementation of NBS for flood mitigation is context-specific and each context needs tailored solutions, the exchange of best-practices across countries can favour the uptake of NBS (Raška et al., 2022). In this case, NBS projects in the NL and in particular the RftR case, being internationally recognised for its pioneering holistic and integrated approach to flood mitigation via NBS, can provide guidance for the development of flood mitigation strategies that utilise NBS elsewhere (Rijke et al., 2012). The comparison between ex-post barriers and enablers that led the NL to successfully implement large-scale NBS for flood mitigation, and ex-ante barriers and enablers to NBS in the PV, can therefore lead to formulating recommendations for the enhancement of NBS as flood mitigation strategies in the PV.

3. Methods

3.1. Conceptual Framework

The conceptual framework illustrated in Figure 4 presents the main line of thought that guides the research process. The first step when considering the implementation of NBS is to understand where the problem occurs (Vriend et al., 2015). Thus an initial evaluation of the extent of flood-prone areas, impacts and causes of floods in the PV is needed. Second, research on the state of the art of NBS implementation for flood mitigation in PV provides an overview of the degree of their uptake and insights on ex-ante barriers and enablers. Third, an overview of the state of the art for NBS uptake in the NL and the assessment of ex-post barriers and enablers that occurred during the realization of large-scale flood mitigation projects, such as the RftR, provide insights on key enabling factors that foster the implementation of these measures. Then, the comparison between PV and NL allows us to highlight the similarities and differences between the barriers and enabling factors in the two contexts, from which lessons can be learned, finally leading to the formulation of recommendations for the implementation of large-scale NBS for flood mitigation in PV.

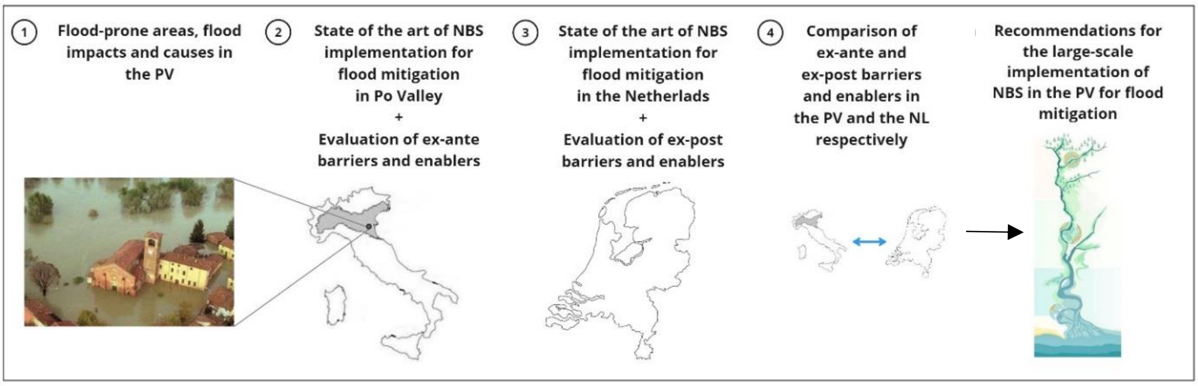

Figure 4 Conceptual framework that shows the main concepts and steps followed in this research. Images retrieved and adapted from Pedro-Monzonís et al. (2016) and AdbPo (n.d).

3.2. Research methods and data

Given the exploratory and interdisciplinary nature of this research and the multitude of concepts it involves, a mixed-method approach combining qualitative and quantitative research was used to answer the RQ, as illustrated in Figure 5. This choice is also motivated by the need to integrate different types of data and sources to comprehensively answer the four SQs, especially in consideration of the scarcity of data in the scientific literature. In addition, the use of multiple sources enabled the validation of data, thus increasing the reliability of the results.

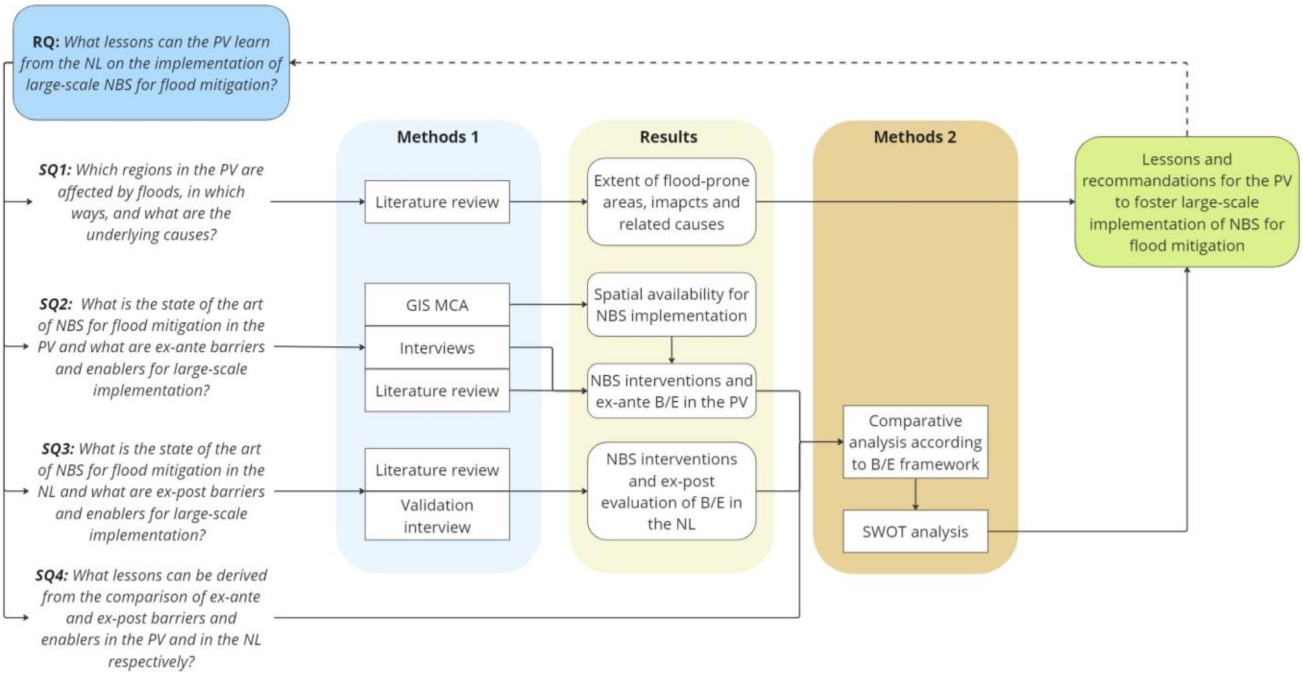

Figure 5 Research framework, showing the four SQs and the methodology applied to answer each of them. The first step of the research strives to build up background knowledge on flood impacts in the PV and give insights on NBS for flood mitigation in the PV and the NL, considering ex-ante and ex-post barriers and enablers respectively. Then a second step compares findings from the PV and the NL to highlight differences and similarities. Finally, a SWOT analysis gives insights into lessons that the PV can learn from the NL, leading to the formulation of recommendations and eventually answering the RQ.

The first step aimed to build up background knowledge on flood risk in the PV to contextualise where the problem occurs, what the impacts and the causes for flood are, thus answering "*Which regions in the PV are affected by floods, in which ways, and what are the underlying causes?".* A literature review of both grey literature and scientific literature was performed to gather data on the expected extent of flood-prone areas, impacts in terms of population, buildings, industries and services and cultural heritage; and on catastrophic flooding events that occurred in the PV from 1951 onward to gain insights on the causes that trigger floodings, see Table 11 in the appendix. Data gathered on past flood events entailed the year and provinces where the floods occurred, and a description of the events in terms of duration, dynamics, damages, and leading causes. Sources of data included the report published in 2021 by the Italian Institute for Environmental Protection and Research (Istituto Superiore per la Protezione e la Ricerca Ambientale, ISPRA), as it presents the most recent data on flood risk and impacts on a national level; and scientific publications searched via Google Scholar with keywords such as *catastrophic floods, flood events, flood impact,* etc. followed by the name of each region and the PV (both in English and Italian language). When data for a specific flood event was insufficient, grey literature was also used (i.e. Italian websites of national and regional journals and authorities).

The second step was to investigate the state of the art of NBS for flood mitigation in the PV and to assess ex-ante barriers and enablers to their implementation. This was done in two stages:

- A preliminary assessment of the spatial availability for NBS implementation in the PV was first performed with the scope of assessing the feasibility of these strategies in this territory. The analysis was performed through spatial analysis using ArcGIS ArcGIS Pro 3.0 and followed the methodology developed by Mubeen et al. (2021). This method allowed the allocation of four types of NBS suitable for large-scale implementation, namely floodplain restoration (FP),

retention basins and ponds (R), afforestation (AFF), and riparian buffer strips (RB) (Mubeen et al., 2021). The conceptual framework of the spatial analysis is illustrated in Figure 6. Firstly, maps for digital elevation model (DEM), rivers, roads, land use and aquifer type were accessed via the open-source databases, reported in Table 1, and downloaded for the PV. The downloaded maps, called *base maps*, were adjusted to have a 100 m resolution and were projected to the coordinate reference system ETRS 1989-LAEA. Then, they were used as input for the toolbox developed by Mubeen et al. (2021). By using ArcGIS functions, maps for slope, distance to rivers and flow length, and distance to roads were derived from the DEM, rivers map and roads map respectively. These *derived maps*, together with the *base maps* for land use and aquifer type, were used as inputs to create *condition maps* by using boundary conditions specific to each NBS. For each NBS in fact, boundary conditions must be fulfilled for slope, land use, etc., and the *condition maps* indicate for each input map, which areas fulfil these conditions. Finally, the overlay of the *condition maps* for each NBS led to the creation of *suitability maps*, which show where all the conditions for floodplain restoration, retention basins and ponds, afforestation and riparian buffer strips are satisfied.
All the boundary conditions are found in Table 9 in the appendix, as well as the flowchart that indicates which *condition maps* where overlayed for every NBS, see Figure 15 in the appendix.

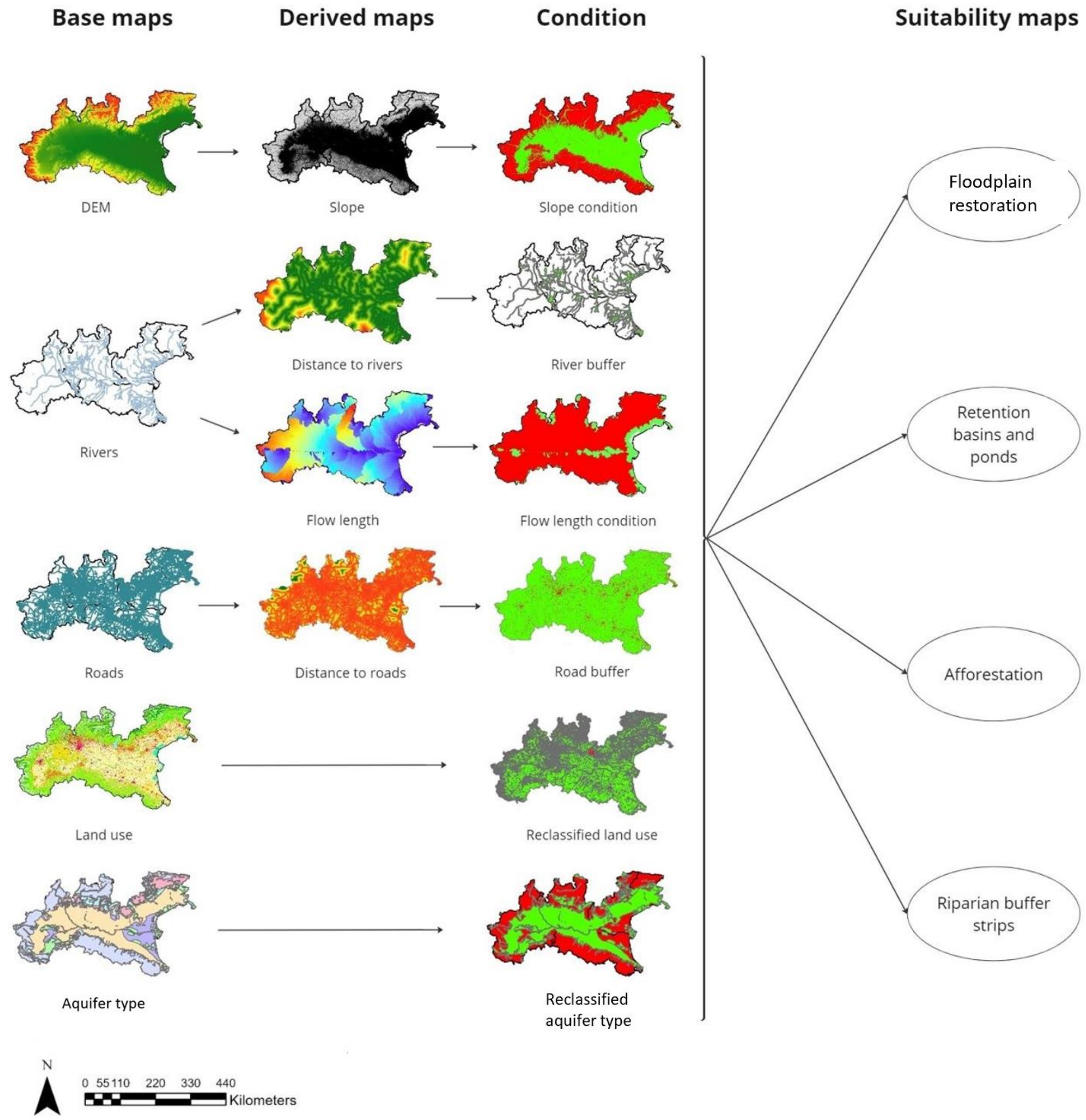

Figure 6 Conceptual framework of the spatial analysis for the allocation of NBS in the PV. It shows the various steps that led from the base maps to the creation of derived maps and then condition maps. By overlaying condition maps for each of the NBS, suitability maps where created.

Table 1 Data from the maps used as base maps in the toolbox.

Base map	Data type	Resolution	Source
Digital Elevation Model (DEM)	Raster	100 m	(*SRTM Data – CGIAR-CSI SRTM*, n.d.)
Rivers	Shape file	-	(*Download Free Italy ArcGIS Shapefile Map Layers*, n.d.)
Roads	Shape file	-	(*Download Free Italy ArcGIS Shapefile Map Layers*, n.d.)
Land use CLC 2018	Raster	100 m	(*CORINE Land Cover*, n.d.)
Land use ESA	Raster	10 m	(*WorldCover | WORLDCOVER*, n.d.)
Aquifer type	Shape file	-	(Bgr, n.d.)

- Second, data on the state of the art of NBS in the PV and ex-ante barriers and enablers for NBS implementations for flood mitigation were retrieved from a review of completed NBS projects found in project document databases, namely *GeoIKP* (n.d.), Oppla (2022) and Restoring European Rivers' RiverWiki (n.d.). These databases were used as they offer a broad collection of international and European cases of NBS interventions. Seven cases were identified for flood mitigation, and data on barriers and opportunities were retrieved from the description of the projects and the official websites of the projects when available. A summary of the cases analysed and related information on barriers and opportunities found are presented in the appendix in Table 12a and 12b respectively. Then, semi-structured interviews with experts were performed, to acknowledge projects not encountered during the database research, and to complement findings on barriers and enablers, thus providing a complete overview of past and on-going NBS interventions for flood mitigation in the PV, ex-ante barriers and enablers. Interviews were aimed at professionals working for Po river basin authorities, namely the Po River District Basin Authority (AdbPo) and the Interregional Agency for the Po River (AIPO), being respectively the responsible authorities for the planning and execution of interventions at the Po basin level (which includes Piemonte, Lombardia, Emilia-Romagna, and the south part of Veneto), and the Civil Protection of Alessandria (located in the Piemonte region, personal contact of the researcher). A privacy statement and consent form was provided to interviewees. The interviewees, listed in Table 2, were contacted via e-mail and interviews were performed via Teams or phone calls. Information about projects or specific hindering/enabling factors mentioned during the interviews was further investigated through complementary research on official websites if further background information was needed. The scheme of the interview is presented in appendix A.

Table 2 Details on interviewees.

Contact person	**Organization**	**Role**
Luca Franzi	AIPO	AIPO director for Eastern Piemonte
Anonymous, referred to as (Personal communication, August 22, 2023).	AIPO	-
Andrea Colombo	AdbPo	Director and technical manager at AdbPo
Dante Ferraris	Civil Protection	Disaster Manager
Matteo Robbiano	Civil Protection	Disaster Manager

As for the PV, the third step aimed to investigate the state of the art of NBS implementation for flood mitigation in the NL, ex-post barriers and enablers. A literature review of completed NBS implementation cases for flood mitigation in the NL, including the RftR case, was conducted to better understand what NBS have been taken up, and what barriers and enabling factors were encountered. Projects were collected from project document databases *GeoIKP* (n.d.), Oppla (2022) and Restoring European Rivers' RiverWiki (n.d.)., and scientific literature on the RftR case, conducted via Google Scholar by using the name of the project as a keyword, followed by terms such as *challenges, effectiveness,* and *integrated water management*. As for cases in the PV, the description of the projects was read and data on the kinds of NBS used, barriers and enablers was noted. A summary of the ten projects found in databases and data available for barriers and enablers is found in Table 13a and 13b in the appendix respectively. Finally, results from the previous steps were validated by interviewing Nathalie Asselman, specialist advisor on flood risk management at Deltares. The outline of the interview is the same as the one adopted for the interview in the PV but tailored to specifically refer to the NL and the RftR project.

Lastly, results derived from the evaluation of ex-ante and ex-post barriers and enablers for the implementation of NBS for flood mitigation in the PV and the NL were compared for each category of the barriers-enablers framework, see section 2.2, to highlight differences and similarities in hindering and enabling factors the two context. The comparison allowed the formulation of lessons for the PV to learn based on the NL This allows to derive lessons on enabling factors from the NL to be activated in the PV to tackle barriers to NBS implementation. The comparison made it possible to formulate lessons that the PV can learn based on what was key in the NL to enable the implementation of NBS projects for flood mitigation. Moreover, to emphasise the relevance of these lessons in fostering large-scale implementation of NBS for flood mitigation in PV, a SWOT analysis was performed. This allowed to visualize what opportunities these strategies can generate in the PV, allowing the formulation of recommendations for policymakers and institutional authorities on how to foster large-scale implementation of NBS for flood mitigation.

4. Results

4.1. SQ1

This section aims to gain insights into the areas within the PV that are susceptible to flooding, examine the impact of flooding on these regions, and investigate the underlying factors that contribute to flood events.

4.1.1. Flood-prone areas in the Po Valley and flood impacts

Flood-prone areas in the PV were derived from the report by ISPRA (2021), which estimated the extent of floodable areas on a national level for the year 2020 according to three flood frequency scenarios. These scenarios refer to floods with return time between 20 and 50 years, 100 and 200 years and more than 200 years, which are related to a high probability hazard (HPH), medium probability hazard (MPH) and low probability hazard (LPH) respectively (ISPRA, 2021). Flood-prone areas in the PV are illustrated in Figure 7 for each scenario. The maps show that the areas at risk of flooding under the HPH scenario are in proximity of lakes and rivers in Piemonte, Lombardia and Friuli-Venezia Giulia, while in Emilia-Romagna and Veneto, they also include part of the flat in-land territory. The MPH scenario shows that Emilia-Romagna is largely affected by flooding, as well as for scenario LPH, for which the southern PV, corresponding to flat in-land and coastal areas in Emilia-Romagna, the delta area, and the coastal areas of Veneto and Friuli-Venezia Giulia are highly prone to flood.

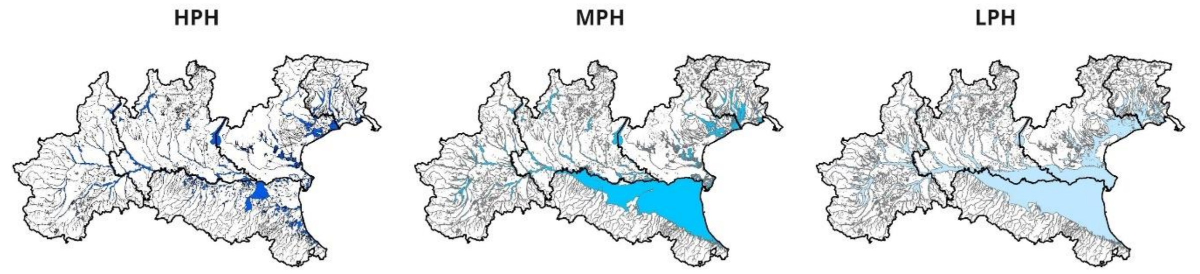

Figure 7 Floodable areas in the PV in 2020 according to HPH, MPH and LPH scenarios. Maps retrieved and adapted from ISPRA (2021).

For each scenario, flood impact in the five regions is illustrated in Figure 8 and refers to the percentage of regional land, population, buildings, industries and services, and cultural heritages that could be affected by flooding under each scenario. Complete data can be found in Table 10 in the appendix. Overall, it can be noted that moving from an HPH to an LPH scenario increases the impact for each category in each region. This means that less frequent but more destructive floods impact larger parts of the territories, thus threatening a higher percentage of inhabitants, infrastructures, industries and cultural heritage sites. Moreover, data shows that the downstream regions Emilia-Romagna, Veneto and Friuli-Venezia Giulia are more vulnerable to flooding, as they experience greater impacts than Piemonte and Lombardia. Furthermore, the graph shows clearly that Emilia-Romagna is the most flood-prone region in the PV, and according to the report from ISPRA (2021), it is also the most flood-prone region in Italy, with almost half of the territory at risk of flooding in the MPH and LPH scenarios (45.6% and 47.3% respectively) that can impact from nearly 60% up to nearly 70% of people, buildings, services and cultural heritages of the region. As for Piemonte, although it has the smallest percentage of flood-prone areas under each scenario, it registered one of the highest societal flood impacts in Italy between 1950 and 2008 (i.e. loss of lives, injuries, missing people, homelessness, etc.) (Salvati et al., 2010).

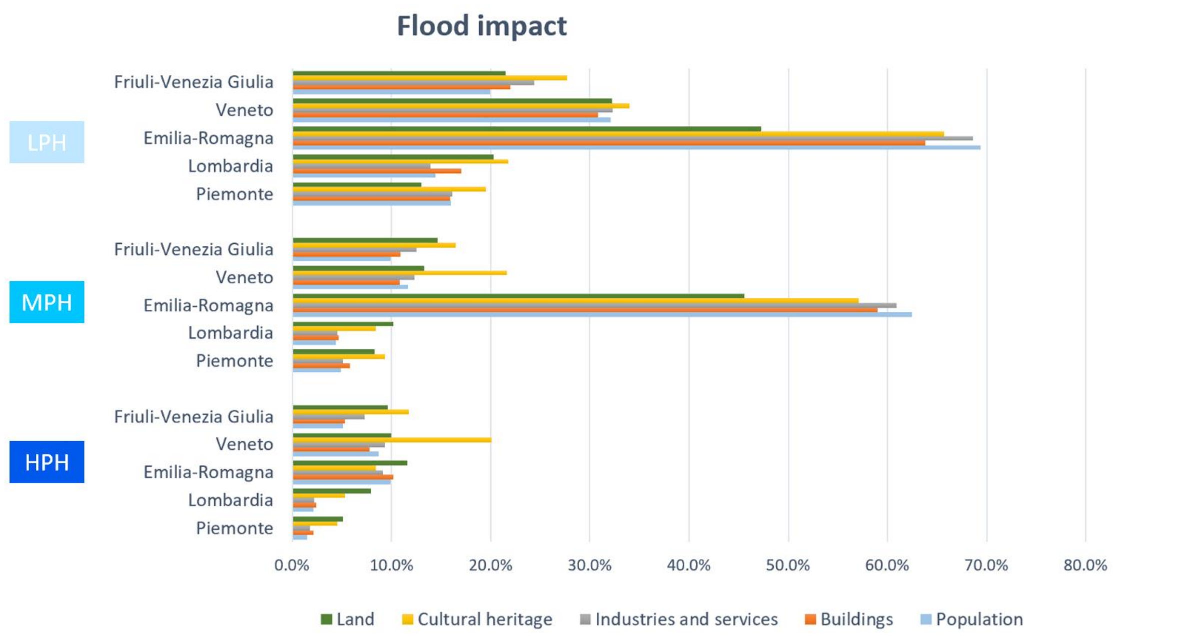

Figure 8 Graphs showing the impact of floods on land, population, buildings, industries and services and cultural heritages under the HPH, MPH and LPH scenarios in each region, expressed as a percentage over the regional values. Data retrieved from ISPRA (2021).

4.1.2. Causes for floods in the Po Valley

The analysis of major floods that occurred in the last 70 years, summarized in Table 11 in the appendix, led to the identification of both general and region-specific causes for destructive flood occurrence in the PV, as visualized in Figure 9. Several studies in fact claim that the causes of floods in the PV are mainly ascribed to anthropological activities (Carminati & Martinelli, 2002; Luino, 2015; Simeoni & Corbau, 2009). In general, in all regions land-use change, intensive urbanization and unregulated urban sprawl in flood-prone land led to the conversion of floodplains into agricultural and urban areas, thus raising flood potential impacts on the economy and society (Luino, 2015; Prosdocimi et al., 2013; Sofia et al., 2017; Viero et al., 2019). In addition, extensive river embarkment and anthropological modification of the river systems together with overloaded artificial drainage networks are among the main causes of a significant increase in flood magnitude in this area (Pistocchi et al., 2015; Prosdocimi et al., 2013; Spaliviero, 2003).

Moreover, the central-eastern area of the PV (entailing the entire Emilia-Romagna, the southern part of Lombardia and the southeastern part of Veneto) is triggered by land subsidence, which is positively correlated with increased flood frequency (Carminati & Martinelli, 2002). In these areas, natural subsidence was accelerated by intensive water and methane withdrawals driven by economic growth during the second half of the 20th century (Armaroli et al., 2019; Carminati & Martinelli, 2002; Martinelli et al., 2010). Inland areas in Emilia-Romagna, the Po Delta and coastal areas are the most affected by subsidence, with some regions being up to 4 meters below sea level and further pressured by sea level rise (Carminati & Martinelli, 2002; Viero et al., 2019). As for the Po Delta, the extensive land reclamation before the 1960s led to the reduction of marshes and exacerbated natural subsidence in drained lands. This made it necessary to channelise the Po River, which became deprived of all its floodplain areas thus leading to increased flood risk (Simeoni & Corbau, 2009). In Veneto, flood risk is further aggravated by two factors. First, soil imperviousness, run-off, and insufficient storage capacity of the artificial drainage network increase the severity of hydrological response to rainfall events (Prosdocimi et al., 2013; Viero et al., 2019). Second, as for Friuli-Venezia Giulia the geomorphology of the area and the increasing concentration of rainfall upstream are triggering more aggressive floods in downstream lands, where the flood risk is higher (Sofia et al., 2017; Spaliviero, 2003).

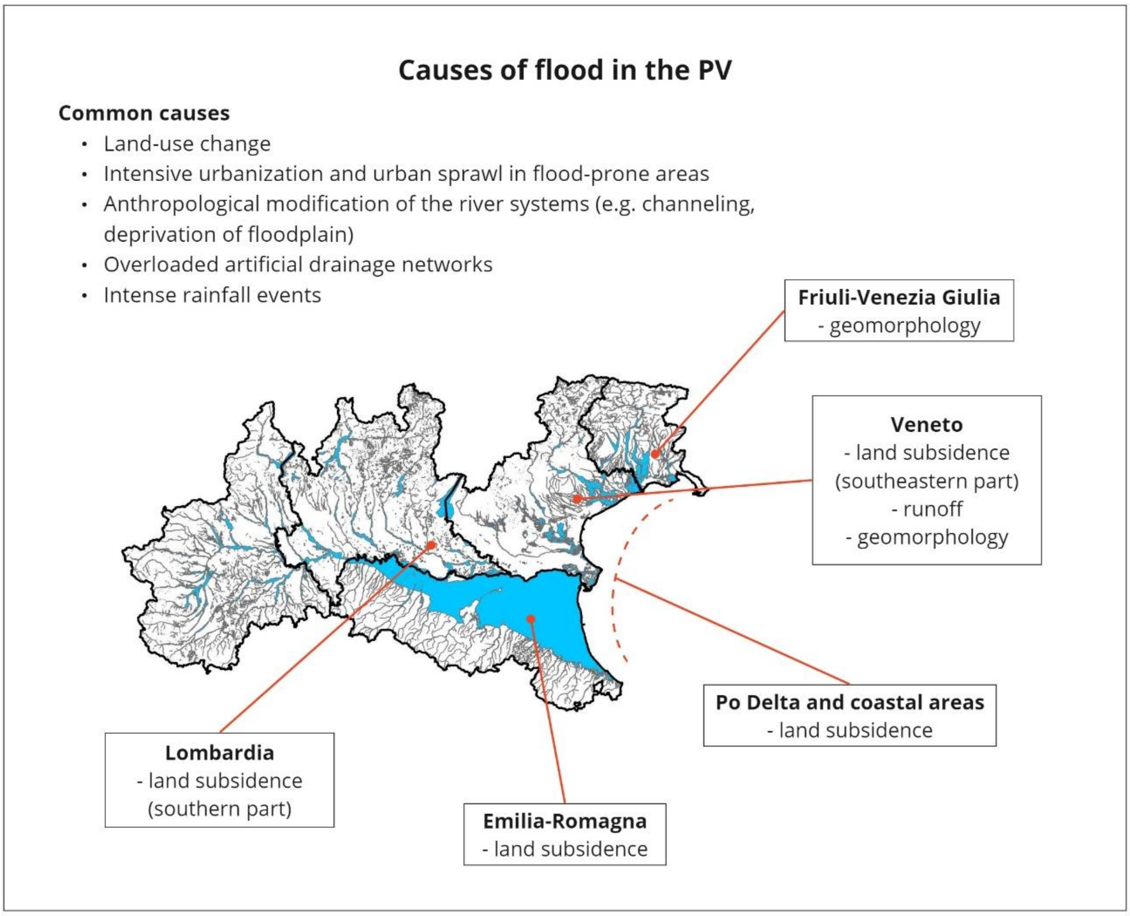

Figure 9 MPH map that shows general and region-specific causes of flood in the PV.

4.2. SQ2

This chapter presents the results derived from the spatial allocation of NBS in section 4.2.1. Then the state of the art of NBS uptake in the PV for flood mitigation is discussed in section 4.2.2, providing reference for the following sections 4.2.3 and 4.2.4 on ex-ante barriers and enablers to the large-scale implementation of these measures.

4.2.1. Spatial allocation of NBS in the Po Valley

Figure 10 shows the maps resulting from setting boundary conditions to the base and derived maps. The *slope conditions* map shows areas of the PV for which the slope is equal to or less than 5%, being suitable for floodplain restoration and retention basins and ponds, and areas where it is equal to or less than 60%, being suitable for afforestation and riparian buffer strips. The *river buffer* map displays areas with a distance from rivers inferior to 100 m, where riparian buffer strips can be allocated, and inferior to 1000 m, suitable for floodplain restoration, retention basins and ponds. In the *reclassified land use CLC* map, areas where land use is suitable for floodplain restoration and retention basins are highlighted in green, and areas suitable for afforestation and riparian buffer stripes are indicated by grey stripes; the *reclassified land use ESA* shows instead areas suitable for all four NBS according to the ESA classification for land use. The *flow length conditions* map illustrates areas where flow length is more than 22,300 m are suitable for retention basins and ponds, and elsewhere for floodplain restoration. The *road buffer* map shows in blue suitable areas for all four NBS as it excludes areas within a 50 m distance from roads. Finally, the *reclassified aquifer type* map displays green areas where the aquifer types meet the boundary conditions for afforestation and riparian buffer strips.

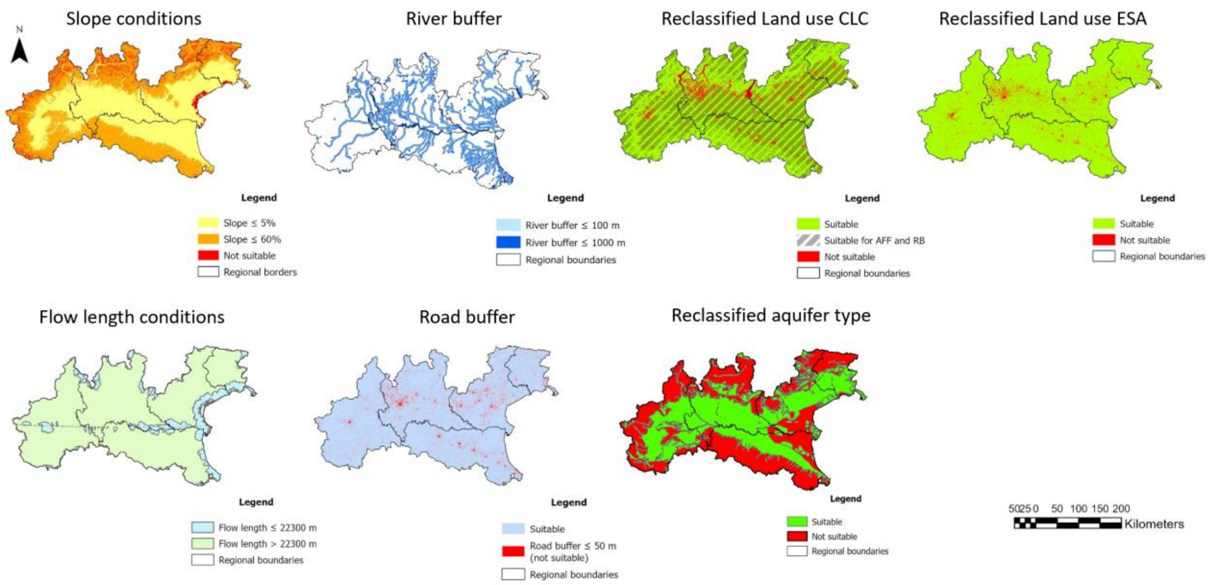

Figure 10 Condition maps and reclassified maps obtained by applying boundary conditions to the base and derived maps.

The final suitability map is shown in Figure 11. Overall, the suitability map shows the spatial availability for the implementation of the NBS considered, i.e. floodplain restoration, retention basins and ponds, afforestation and riparian buffer strips, and their potential use on a large-scale. Floodplain restoration is mainly suitable for delta and coastal areas, retention basins and ponds are suitable for the majority of the rivers in in-land areas and riparian buffer strips can potentially be implemented along the majority of the rivers. Afforestation is largely viable in all regions and especially in-land areas, however, it must be considered that most of the land suitable for afforestation is agricultural land, therefore other barriers can arise from land ownership and land use issues, as discussed in section 2.1.2. Moreover, comparing the suitability map to the MPH map (see section 4.1.1, Figure 9) it can be noted that NBS may be implemented in areas that are not prone to flooding in the upstream regions, such as non-flood-prone areas in Piemonte and Lombardia, yet this can contribute to providing flood mitigation in vulnerable downstream areas (Suttles et al., 2021).

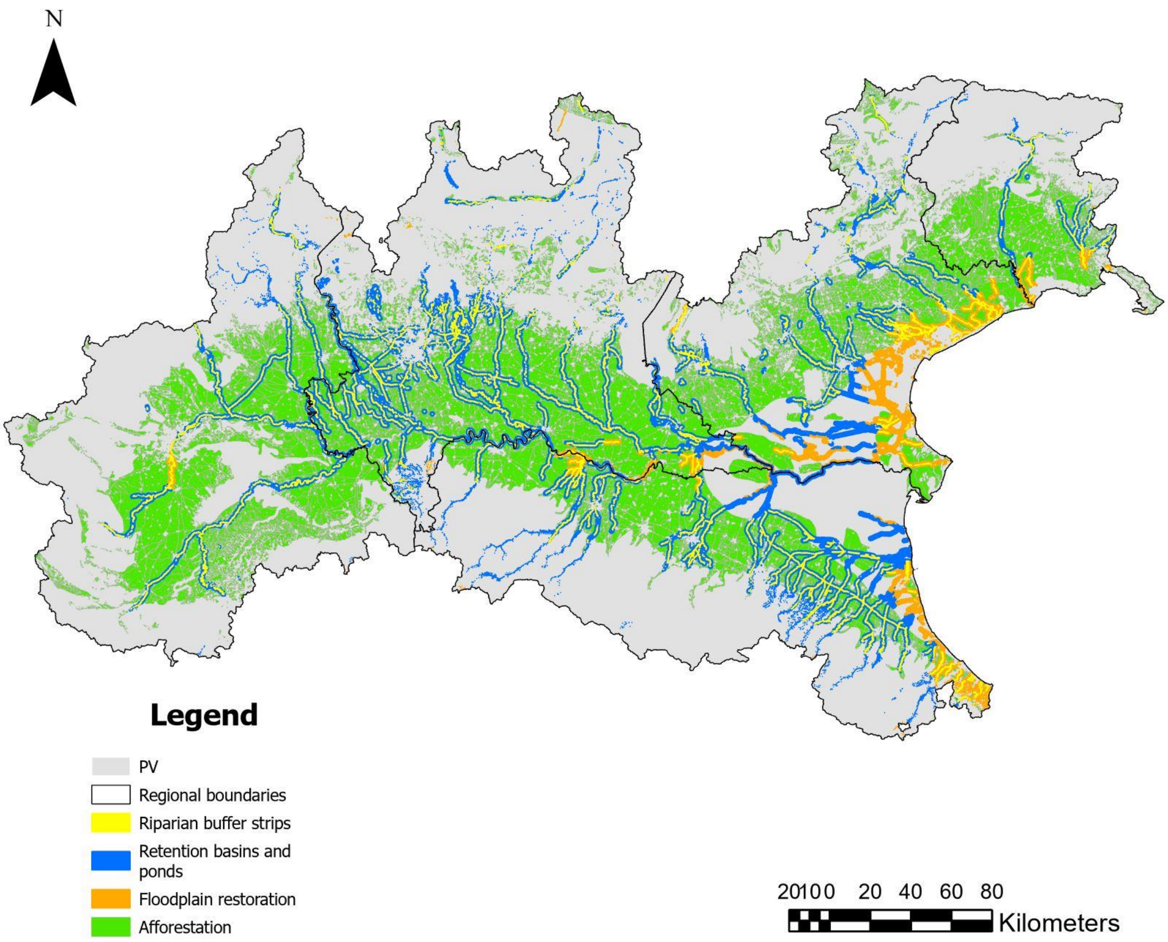

Figure 11 Suitability map that shows the potential allocation of each NBS in the PV.

4.2.2. State of the art of NBS for flood mitigation in the PV

Up to this point, NBS for flood mitigation in the PV have only been adopted on a small scale and mainly entailed floodplain restoration and floodplain lowering, retention basin, constructed wetlands, afforestation, and restored riparian vegetation, see description of the completed projects and related sources in Table 12a and 12b in the appendix. However, in April 2021 the Italian Ministry of the Ecological Transition initiated the first large-scale NBS intervention in the PV, called the Renaturation of the Po Area (AdbPo, 2022). This project aims to restore the natural processes of the Po River and extend areas of native wild vegetation, achieving the overarching objective of flood mitigation and restoration of biodiversity and ecological functions (AdbPo, 2022). This project complies with the *European Water Framework Directive 2000/60* and *Floods Framework Directive 2007/*60, which have been taken up by the National Hydrogeological Planning (Piano Assetto Idreogeologico, PAI) which provides a normative framework for NBS implementation for flood mitigation, see Text Box 1. To realize this project, the Ministry of the Ecological Transition and the four regions crossed by the Po River (Piemonte, Lombardia, Emilia-Romagna and Veneto) are working in close collaboration with AdbPo and AIPO, respectively the planning and operational authority of the Po River basin (AdbPo, 2022). The renaturation entails 56 interventions along the Po River, as illustrated in Figure 12, and aims to activate participatory processes at an interregional, regional, municipal and local level (AdbPo, 2022). The leading concept is in fact to work with nature and use a multidisciplinary integrated approach to restore natural fluvial dynamics by reforestation, reactivation of river branches, and reduced artificiality of the Po River system (AdbPo, 2022). A multi-disciplinary scientific committee of universities and research institutes has been set up to set guidelines and monitor the project (AdbPo, 2022). Moreover, this project may benefit from the recently founded Italian Hub for NBS, created by the National Research Institute on Terrestrial Ecosystems (Istituto di Ricerca sugli Ecosistemi Terrestri) of the National Research Council (Consiglio Nazionale delle Ricerche), aiming to foster the NBS implementation across Italy by supporting stakeholder collaboration and knowledge exchange (*Nasce L'Hub Italiano per Le Nature-based Solution*, n.d.). Finally, the Renaturation of the Po Area is funded by the European Union (EU) as one of the actions undertaken by Italy under the National Recovery and Resilience Plan (Piano Nazionale di Ripresa e Resilienza, PNRR), allocating € 357 million to project (European Commission, n.d). The deadline for the realisation of the project is set by the EU to March 2026 (AdbPo, 2022). Overall, these findings highlight that NBS are gaining momentum in Italy and that large-scale NBS interventions for flood mitigation in the PV have been planned and are currently on-going.

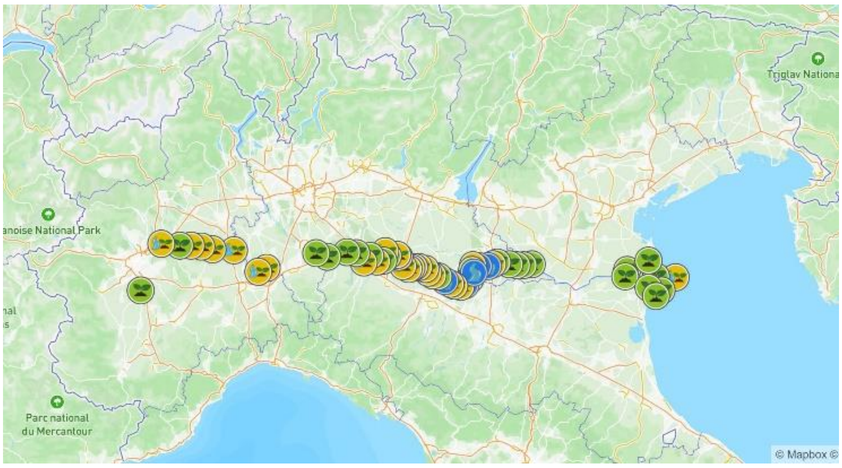

Figure 12 The 56 planned interventions along the Po River as part of the Renaturation of the Po Area project in Piemonte, Lombardia, Emilia-Romagna and Veneto. Image retrieved from AdbPo (2022).

Text Box 1

The European Water Framework Directive 2000/60 and Floods Framework Directive 2007/60 provide a common European normative framework for the adoption of NBS for flood mitigation. The former directive fosters the implementation of a coherent and sustainable policy for the protection and conservation of aquatic ecosystems and flood mitigation (*FAO*, n.d. a); the latter defines strategies for flood risk management and reduction, including NBS (*FAO*, n.d. b). These directives are recalled in the National Hydrogeological Plan (PAI), which includes NBS as strategies to tackle flood risk by the reconnection of river branches, afforestation, and recovery and conservation of wetlands (AdbPo, n.d.).

4.2.3. Ex-ante barriers to the implementation of large-scale NBS for flood mitigation in the PV

Ex-ante barriers to large-scale implementation of NBS for flood mitigation in the PV can be found for each of the five categories identified in the barriers-enablers framework (see section 2.2). According to the interviewees, political barriers are the short-term political vision and commitment, and lack of an integrated approach to flood management (see Table 3, barrier P). These political barriers drive other barriers, as in the case of the Renaturation of the Po Area, where short-term planning creates uncertainty on the possibility of implementing all the 56 interventions, and on how to finance, manage, monitor and maintain the project after 2026, thus undermining the effectiveness of the project (A. Colombo, personal communication, September 19, 2023; personal communication, August 22, 2023). Other uncertainty-related barriers were found during the implementation of small-scale projects and are due to both uncertainty on the effectiveness of NBS to mitigate floods and a lack of technical knowledge and guidelines (see Table 3, barrier U). In addition, interviewees highlighted the difficulty of activating extensive participatory approaches due to cultural aspects, low acceptance and mistrust in NBS (see Table 3, barrier S). Participatory processes are also hindered by short-term planning as in the case of the Renaturation of the Po Area. In fact, to meet the deadline set in 2026, participation is limited to formal meetings among authorities and stakeholders (*Conferenza di Servizi*), thus excluding local communities (A. Colombo, personal communication, September 19, 2023). On one hand, this causes a lack of dialogue with local communities that prevents knowledge-exchange and, on the other hand, contributes to a lack of awareness and acceptance of NBS, thus contributing to both uncertainty-related and social barriers (personal communication, August 22, 2023). Furthermore, both projects and interviews mentioned limited and short-term funding as hindering factors to NBS uptake (see Table 3, barrier E). L. Franzi in fact claimed that although NBS are not a new concept in the PV, their implementation was heavily hampered by a lack of investments in these measures in previous years (personal communication, July 11, 2023). Finally, clashes between landowners and authorities are likely to arise because of land reallocation, which is a spatial barrier to large-scale NBS implementation (see Table 3, barrier SP).

Table 3 Summary of the barriers found by the analysis of competed small-scale NBS projects for flood mitigation in the PV and outcomes from the interviews. Barriers are divided into the five categories discussed: political (P), uncertainty-related (U), social (S), economic (E) and spatial (SP). For sources and data related to the small-scale projects, refer to Table 12a and 12b, in the appendix.

Barrier	Description	Sources
P	• Short-term political vision and commitment	D. Ferraris (personal communication, September 5, 2023); (personal communication, August 22, 2023)
	• Lack of supportive integrated measures for flood management	D. Ferraris (personal communication, September 5, 2023); (personal communication, August 22, 2023);
U	• Unknown consequences and effectiveness of NBS which often leads to favour structural/grey infrastructure over NBS	L. Franzi (personal communication, July 11, 2023); (personal communication, August 22, 2023); see also Table 12a and 12b for data and references on small-scale projects in the appendix
	• Lack of knowledge and guidelines	See Tables 12a and 12b for data and references on small-scale projects in the appendix
S	• Lacking “culture” of large-scale participatory processes in the PV, and in Italy in general	A. Colombo (personal communication, September 19, 2023); L. Franzi (personal communication, July 11, 2023); (personal

		communication, August 22, 2023)
	• Low acceptance and mistrust of NBS as perceived as less safe by local communities, thus leading to aversion to change	D. Ferraris (personal communication, September 5, 2023); L. Franzi (personal communication, July 11, 2023); (personal communication, August 22, 2023)
E	• Lack of national investments in NBS and short-term funding	L. Franzi (personal communication, July 11, 2023); (personal communication, August 22, 2023); see also Table 12a and 12b for data and references on small-scale projects in the appendix
SP	• Clashes due to land ownership and land use	D. Ferraris (personal communication, September 5, 2023);

4.2.4. Ex-ante enablers to the implementation of NBS for flood mitigation in the PV

Ex-ante enablers to the large-scale implementation of NBS in the PV are political will, which is reflected by the decision of the government to allocate part of the PNRR funds to the Renaturation of the Po Area, thus enabling economic incentives to NBS uptake, and the presence of supportive norms such as the PAI, that promote the use of NBS to mitigate floods (see Table 4, enablers P and E). Multi-disciplinary and multi-level cooperation among stakeholders was also mentioned in both small-scale projects and by interviewees when referring to the Renaturation of the Po Area project as an enabler for NBS uptake (see Table 4, enabler P). Small-scale NBS interventions repot that knowledge sharing is a key enabler, and according to M. Robbiano, the Italian Hub for NBS can greatly contribute to knowledge-exchange at a national level, thus facilitating NBS uptake through the provision of guidelines and research to overcome uncertainty-related barriers (personal communication, September 3, 2023). Co-creation, as well as education, training and participatory processes, is considered fundamental to the realization of small-scale interventions, eventually leading to the co-creation of interventions (see Table 4, enabler U and S). The importance of including compensation schemes in the budgeting of the interventions is highlighted in both small-scale projects and the Renaturation of the Po Area project, being a facilitator for NBS interventions (see Table 4, enabler SP). Finally, results on the spatial allocation for large-scale implementation of NBS in the PV provided in section 4.2.1 show the potential spatial availability of these measures in terms of suitable land for the four types of NBS considered (i.e. floodplain restoration, retention basins and ponds, afforestation and river buffer strips), underlining that these strategies may apply to a large extent.

Table 4 Summary of the ex-ante enablers that can foster the implementation of NBS for flood mitigation in the PV. Enablers are divided into the five categories discussed: political (P), uncertainty-related (U), social (S), economic (E) and spatial (SP). For sources related to the projects, refer to Table 12a and 12b, in the appendix.

Enabler	Description	Sources
P	• Political will to implement NBS	A. Colombo (personal communication, September 19, 2023); L. Franzi (personal communication, July 11, 2023); see also Table 12a and 12b for data and references on small-scale projects, in the appendix

	• Supportive regulations (national level)	L. Franzi (personal communication, July 11, 2023)
	• Multi-scale and multi-disciplinary collaboration among stakeholders	D. Ferraris (personal communication, September 5, 2023); see also Table 12a and 12b for data and references on small-scale projects, in the appendix
U	• Knowledge sharing	M. Robbiano (personal communication, September 3, 2023); see also Table 12a and 12b for data and references on small-scale projects, in the appendix
	• Co-creation in small-scale projects	See Tables 12a and 12b for data and references on small-scale projects, in the appendix
	• Education and training of local communities in small-scale projects	
S	• Participatory processes in small-scale projects	
E	• Fundings opportunities	A. Colombo (personal communication, September 19, 2023); L. Franzi (personal communication, July 11, 2023); see also Table 12a and 12b for references on small-scale projects, in the appendix
SP	• Spatial availability	See ArcGIS results section 4.2.1)
	• Activation of compensation schemes	A. Colombo (personal communication, September 19, 2023); see also Table 12a and 12b for references on small-scale projects, in the appendix

4.3. SQ3

This section describes the results obtained to answer SQ3 (*What is the state of the art of NBS for flood mitigation in the NL and what are ex-post barriers and enablers for large-scale implementation?*). Sub-section 4.3.1 provides an overview on the state of the art of NBS implementation for flood mitigation in the NL, providing reference for the following sub-sections 4.2.3 and 4.2.4, which present ex-post barriers and enablers that hindered or facilitated the uptake of NBS strategies in the NL respectively.

4.3.1. State of the art of NBS implementation for flood mitigation in the NL

The RftR project in the NL represents one the most well-known examples of large-scale NBS uptake for flood mitigation and reflects the state of the art of NBS for flood mitigation in the country. The Dutch Ministry of Infrastructure and Environment started the project in 2006 with the twofold objective to restore flood protection and safety in the NL without raising more dikes while simultaneously improving the ecosystem and biodiversity of the river system by 2015 (Sokolewicz et al., 2011; Zevenbergen et al., 2015). The project cost 2.3 billion euros, being mainly funded by the national government, and led to the implementation of thirty-nine interventions along the rivers, as shown in Figure 13 (Sokolewicz et al., 2011). Interventions encompassed floodplain lowering, removal of obstacles, embankment reallocation, water retention areas, rivers by-pass, height reduction of groynes, deepening of the summer bed, heightening of dikes and dyke improvements (Zevenbergen et al. 2015). As a result, the discharge capacity of the river Rhine increased from 15,000 to 16,000 m^3s^{-1} and it reached 3,800 m^3s^{-1} for the Meuse (Zevenbergen et al. 2015).

Figure 13 Location of the projects executed as part of the RftR programme. Image retrieved from Sokolewicz et al. (2011).

The national government introduced supportive policies and governance arrangements to achieve the widening of the river and used a new multi-level governance approach to guarantee collaboration between different governmental agencies (e.g. water, agriculture, nature, spatial planning sectors) from multi-spatial government levels (e.g. national, regional, local) (Rijke et al., 2012; Van Herk et al., 2015; Zevenbergen et al., 2015). Within this mixed centralized-decentralized governance approach, the frameworks to improve water security and land quality were set by the national government while plans and decision-making for local interventions were set by local and regional stakeholders (Rijke et al., 2012; Zevenbergen et al., 2015). Moreover, the project entailed the broad involvement of stakeholders and local communities in the design, planning, and decision-making processes (Rijke et al., 2012; Zevenbergen et al., 2015). A National Central Office was set up to provide guidelines and expert knowledge for the implementation of regional projects and to monitor the programme, contributing to the diffusion and application of lessons learnt from international projects (Rijke et al., 2012; Zevenbergen et al., 2015).

On a smaller scale, projects described in Table 13a indicate that the main strategies adopted are floodplain and river restoration, floodplain lowering, deepening of the summer bed, creation of secondary channels and retention basins, afforestation, dike removal and re-allocation (see Table 13a for references).

4.3.2. Ex-post barriers to NBS implementation of NBS for flood mitigation in the NL

Ex-post barriers to NBS implementation in the NL are listed in Table 5. Overall, both the projects described in Table 13a in the appendix and the RftR project faced spatial barriers to their implementation, due to the opposition from residents and farmers to land expropriation and claims for compensation schemes (Ritzema & Van Loon-Steensma, 2018). The projects mentioned opposition to land re-allocation among the built environment, nature, recreational and agriculture areas due to limited land availability, see Table 13a Overview of completed NBS interventions that have enabled flood reduction in the Netherlands and different NBS strategies that have been used.Table 13a in the appendix. Economic barriers were also mentioned in the case of RftR, as more funds were needed to complete the project than initially, available and additional funds had to be procured from provinces, water authorities and municipalities (Sokolewicz et al., 2011). While many projects did not report data on barriers, as shown in Table 13b in the appendix, N. Asselman confirmed that only economic and spatial barriers applied to the RftR project (personal communication July 5, 2023).

Table 5 Summary of the barriers found by the analysis of completed NBS projects for flood mitigation in the NL and the RftR project. Barriers are divided into political (P), uncertainty-related (U), social (S), economic (E) and spatial (SP). Some barriers were not mentioned thus there is no data available, see Table 13b in the appendix (n.d.).

Barrier	Description	Sources
P	n.d.	
U	n.d.	
S	n.d.	
E	• Limited funding of the RftR	Sokolewicz et al. (2011)
SP	• Opposition by residents and farmers to leave their lands leading to claims on compensation schemes	N. Asselman (personal communication July 5, 2023); Ritzema & Van Loon-Steensma (2018); see also Table 13a and 13b for data and references on small-scale projects, in the appendix
	• Conflicts on land use due to limited land availability	N. Asselman (personal communication July 5, 2023); see also Table 13a and 13b for data and references on small-scale projects, in the appendix

4.3.3. Ex-post enablers to the implementation of NBS for flood mitigation in the NL

Ex-post enablers that co-occurred in the implementation of NBS for flood mitigation in the NL are summarized in Table 6. At the institutional level, the urgency and political will to adopt a new approach to flood management after the two floods in 1993 and 1995 was key to enabling large-scale NBS implementation (Rijke et al., 2012). According to N. Asselman, "Without these two floods, it would have been merely impossible to get this change in people's minds " (personal communication July 5, 2023). The implementation of a supportive regulatory framework for integrated water management is mentioned as fundamental, as well as the cooperation between multi-scale and multi-disciplinary stakeholders, fostered by the adoption of a multi-level governance approach in the case of the RftR project (Rijke et al., 2012; Zevenbergen et al., 2015). The adoption of an experimental approach, provision of guidelines, and monitoring programme of the RftR project facilitated its implementation by the diffusion and application of lessons learnt from international projects (Rijke et al., 2012; Zevenbergen et al., 2015). Another important enabler mentioned is the broad participation and involvement of the local communities in education, co-design, co-planning, and decision-making processes, which on one hand enabled the overcoming of knowledge-related barriers through knowledge-sharing and uptake of local knowledge in the projects, and on the other hand, established trust in the measures (Rijke et al., 2012; Zevenbergen et al., 2015). As N. Asselman claimed, "If people can come up with their own ideas and these are taken seriously and the local knowledge is incorporated into the final plan, then it's much easier [for the project to be accepted] than when you just have a top-down decision" (personal communication July 5, 2023). Also, in the case of the RftR project, the fact that funds were allocated to the project in the long term prevented the interruption of the project due to changes in the political and institutional settings or termination of funds (N. Asselman, personal communication, 5 July 2023). Finally, compensation schemes for land expropriation greatly contributed to tackling clashes on land expropriation both in the case of the RftR project and other smaller-scale projects across the NL (see Table 6, enabler SP). The importance of enablers to NBS implementation in the NL is reflected by N. Asselman's claim: "At that time people were willing to pay for nature. The environment was important. But we have had periods where people were less willing to pay for nature and then NBS are much more difficult to get across" (personal communication, 5 July 2023).

Table 6 Summary of the ex-post enablers that fostered the implementation of NBS for flood mitigation in the NL. Enablers are divided into the five categories discussed: political (P), uncertainty-related (U), social (S), economic (E) and spatial (SP). For sources and data related to the projects, refer to Table 13a and 13b in the appendix.

Enabler	Description	Sources
P	• Sense of urgency, clear policy vision and long-term planning	N. Asselman, (personal communication, 5 July 2023); Rijke et al. (2012); Zevenbergen et al., (2015);
	• Supportive regulatory framework	See Tables 13a and 13b for data and references on small-scale projects, in the appendix
	• Broad multi-scale and multi-disciplinary cooperation among stakeholders	Rijke et al. (2012); Zevenbergen et al., (2015); see also Table 13a and 13b for data and references on small-scale projects, in the appendix
U	• Monitoring and experimentation	N. Asselman, (personal communication, 5 July 2023); Rijke et al. (2012); Zevenbergen et al., (2015); see also Table 13a and 13b for data and references on small-scale projects, in the appendix
	• Co-creation of knowledge with local communities and knowledge-sharing	N. Asselman, (personal communication, 5 July 2023); Rijke et al. (2012); Zevenbergen et al., (2015);
	• Education and training	Rijke et al. (2012); Zevenbergen et al., (2015);
S	• Broad participatory process	N. Asselman, (personal communication, 5 July 2023); Rijke et al. (2012); Zevenbergen et al., (2015).
	• Co-design of solutions	See Tables 13a and 13b for data and references on small-scale projects, in the appendix
E	• Availability and long-term funding	N. Asselman, (personal communication, 5 July 2023)
SP	• Activation of compensation schemes	see also Table 13a and 13b for data and references on small-scale projects, in the appendix

4.4. SQ 4

First, the comparison of ex-ante and ex-post barriers and enablers in the PV and the NL respectively is carried out according to the barriers-enablers framework discussed in section 2.2, to derive lessons from the NL. Then the SWOT analysis aims to give a complete and integrated overview of the key findings from sections 4.1, 4.2, and 4.3 to finally derive recommendations for policy-makers and stakeholders.

4.4.1. Comparing ex-ante and ex-post barriers and enablers

The comparison of ex-ante and ex-post barriers and enablers to NBS implementation in the PV and the NL reveals two distinct situations, as illustrated in Tables 7 and 8. First, the PV faces more barriers than the NL when it comes to large-scale NBS implementation, as shown in Table 7. At the same time, the barriers that PV is facing have a higher hindering power to NBS uptake, being political, uncertainty-related and social barriers. As for enablers, most of those activated in the PV are limited to small-scale projects, especially uncertainty-related and social enablers, or are limited by a short-term approach, such as in the case of short-term vision and funding; as opposed to the NL, where enablers entail integrated, participated, and long-term measures, such as integrated flood management, broad participatory processes and long-term vision, see Table 8.

Table 8 Comparison of barriers in the PV and in the NL. The ~ refers to partial barriers, i.e. in the PV there is political will for NBS implementation but this is limited by short-term commitment; in the NL, funding for the RftR was limited but distributed over a long period; spatial barriers in the PV only regards issues on land ownership and not lack of available land for NBS implementation.

	Barriers	PV	NL
P	Lack of urgence, political will and short term-commitment	~	
P	Lack of institutional and regulatory framework		
P	Lack of integrated approach to flood management	X	
P	Lack of collaboration among stakeholders		
U	Unknown effectiveness of NBS	X	
U	Lack of knowledge and guidelines	X	
S	Lack of acceptance and awareness	X	
S	Mistrust and aversion to change	X	
E	Lack of and short-term funding	X	~
SP	Land availability land ownership issues	~	X

Table 7 Comparison of enablers in the PV and in the NL. The ~ refers to the limited implementation or effectiveness of enablers, e.g. due to scale or time constraints: in the PV political will is not coupled with long-term vision; most of the uncertainty-related and social enablers only apply to small-scale NBS interventions, and economic incentives are limited by a short-term planning.

	Enablers	PV	NL
P	Political will and long-term vision	~	X
P	Supportive integrated regulations	X	X
P	Intregrated approach to flood management		X
P	Multi-scale and multi-disciplinary collaboration	X	X
U	Monitoring and experimentation	X	X
U	Co-creation of knowledge and knowledge sharing	~	X
U	Education and training	~	X
S	Participatory approach	~	X
S	Co-planning and co-design of solutions	~	X
E	Economic incentives	~	X
SP	Compensation mechanisms	X	X

In more detail, considering political aspects, despite political willingness, short-term vision and lack of integrated measures for flood mitigation in the PV are barriers to large-scale NBS uptake, as opposed to the long-term vision and integrated approach to flood management adopted by the NL. Uncertainty-related and social barriers that are hindering the large-scale implementation of NBS in the PV due to the unknown effectiveness of NBS interventions, lack of knowledge and guidelines, lack of awareness and acceptance, mistrust and aversion to change, were overcome in the NL thanks to extensive experimentation and monitoring of the projects, broad knowledge-sharing and education, but also broad participation of local communities to the co-creation of solutions. In the PV these same enablers were applied to the realization of small-scale projects, proving their facilitating function, but are limited at a larger scale. As for the economic aspects, barriers derive from limited funding for the implementation of NBS on a large scale for both the PV and the NL. However, in the PV it is further exacerbated by the short-term nature of the funding. Finally, both the PV and the NL face spatial barriers, which in the NL regard both limited availability of land and conflicts on land ownership and in the PV only refer to the latter, as results from section 4.2.1 have determined the potential large-scale spatial availability the implementation of NBS for flood mitigation.

To summarize, the comparison highlights that key factors that could be adopted in the PV, which enabled the NL to successfully implement NBS on a large scale and achieve flood protection objectives, are: the adoption of long-term perspectives and integrated approaches to flood management; the activation of broad participatory processes which actively involve local communities into generating and sharing knowledge but also into the co-creation of solutions, thus enhancing acceptance, and trust in the measures. These aspects represent key lessons for the PV to enhance the large-scale implementation of NBS to mitigate floods.

4.4.2. SWOT analysis

On one hand, the SWOT analysis depicted in Figure 14 provides insights into the threats that could affect the PV if no action is taken to address the weaknesses, i.e. ex-post barriers, that are hindering large-scale NBS implementation for flood mitigation in the PV. On the other hand, it highlights the opportunities that the PV could achieve by leveraging and empowering strengths, i.e. ex-ante enablers, and by applying lessons from the NL on large-scale NBS uptake to mitigate floods.

Weaknesses to NBS implementation in the PV, i.e. ex-ante barriers described in section 4.2.3, concern political aspects, such as the short-term vision of political administrations and short-term funding, which in the case of the Renaturation of the Po Area project create a misalignment between short-term planning and long-term goals; uncertainty-related barriers due to the lack of guidelines and uncertainty on NBS effectiveness, that hamper NBS uptake in the PV; limited participation of local communities to large-scale NBS projects, which cause both social and uncertainty-related barriers and risk to create opposition around the Renaturation of the Po Area project; and spatial constraints due to conflicts on land-ownership and land use. In the absence of counteracting measures, these barriers can generate *threats*, for instance, failure to implement integrated flood mitigation plans using NBS missed opportunities to learn from local small-scale projects and international best practices (such as the RftR), and loss of funding opportunities. Barriers are also threatening the achievement of the goals set for the ongoing Renaturation of the Po Area project and can hamper future similar projects, consequently leading to favour the adoption of traditional grey infrastructures (e.g. dikes and embankments) over NBS. Ultimately, the risk is for the PV to experience exacerbated flood risk and forego the co-benefits that NBS generate.

However, *strengths*, i.e. ex-ante enablers described in section 4.2.4, are found to support the large-scale application of NBS to mitigate floods in the PV. These are the political willingness to move towards and invest in NBS strategies to reduce flooding, manifested by the actuation of the Renaturation of the Po Area project; a normative framework (i.e. the PAI) that enables NBS implementation to tackle flood risk in the PV; and multi-scale and multi-disciplinary collaboration among stakeholders in both small-scale interventions and the Renaturation of the Po Area project, which can be further enhanced by the Italian Hub for NBS (see section 4.2.2), together with knowledge building and sharing. Moreover, completed small-scale NBS projects in the PV (see section 4.2.2) prove that it is possible to activate local participatory processes, and raise awareness and acceptance of NBS through co-creation, education and resolution of conflicts on land use, thus overcoming social, uncertainty-related and economic barriers. Finally, the results of the spatial allocation of NBS in section 4.2.1 show that large-scale interventions are feasible and can potentially be extended beyond the interventions in the Po River renaturation plan, which only affect areas adjacent to the Po River, thus neglecting tributaries and most rural areas in which NBS can be implemented. By leveraging on the factors discussed in section 4.4.1, and pursuing lessons from the NL, *opportunities* can be generated to foster large-scale flood reduction in the PV by NBS uptake. These include a joint long-term commitment and collaboration between political authorities and stakeholders to achieve an integrated plan for the PV that uses NBS for flood mitigation; take advantage of learning opportunities provided by both small local projects as well as international best-practices to seek knowledge building and broad participatory process in the PV, thus creating more awareness and acceptance of NBS; by doing so, PV can profit not only from external funds but also generate internal funds, due to the increased support of NBS at the government level and the increased awareness of stakeholders, who might then decide to invest in these strategies, as it happened for the NL when more funding was needed. Lastly, exploiting the availability of suitable areas to plan large-scale NBS interventions opens the opportunity for the PV to achieve effective flood risk mitigation and co-benefits.

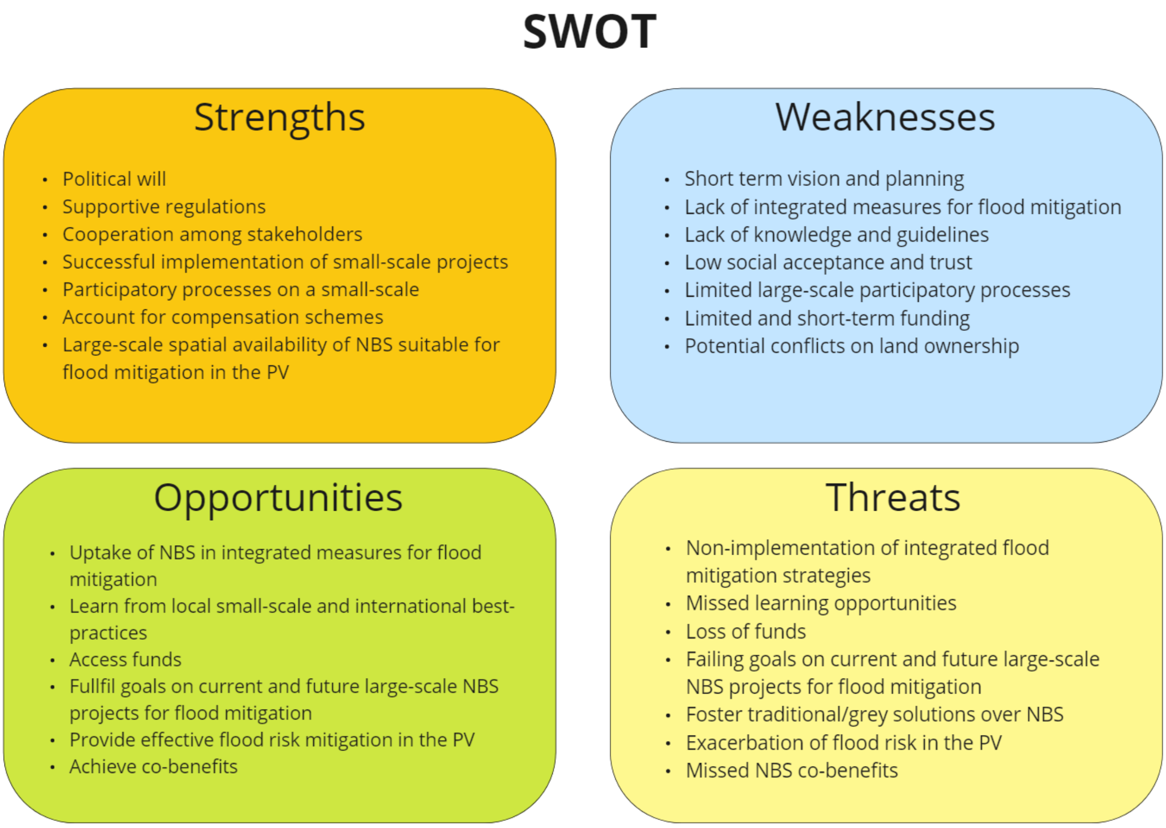

Figure 14 SWOT analysis that highlights strengths (enablers), weaknesses (barriers), opportunities and threats to the large-scale implementation of NBS for flood mitigation in the PV.

5. Discussion

Considering the large-scale implementation of NBS to mitigate flood in the PV is utterly important in light of the results derived from the analysis of flood impacts and causes in PV. The results in fact reveal that current grey measures (i.e. dikes and embankments) provide limited flood protection in case of low-frequency high-impact flooding, as claimed by research (Castellarin et al., 2010). Although NBS are gaining momentum in the PV, as underscored by the small-scale projects and the ongoing Renaturation of the Po Area project, and the spatial analysis shows the potential spatial availability for the large-scale implementation of such solutions, NBS face barriers with a greater hindering power in the PV than the NL. Also, contrarily to the NL, most of the enablers in the PV are limited by short-term projects or only regard small-scale projects. Results on ex-ante barriers and enablers in the PV confirm the finding in the literature on the impact that barriers with a high hindering power, e.g. political, uncertainty-related and social barriers, have on limiting NBS uptake, especially if adequate enabling measures are not set in place, as in the case of the PV (Kumar et al., 2020; Raška et al., 2022; S. Sarabi et al., 2020; S. E. Sarabi et al., 2019). On the contrary, the successful implementation of large-scale NBS for flood mitigation in the NL validates the crucial role that enablers have in facilitating these interventions (Kumar et al., 2020; Ramírez-Agudelo et al., 2020; S. E. Sarabi et al., 2019). The comparison between the PV and the NL coupled with the SWOT analysis allowed to derive important lessons for the PV to foster large-scale NBS implementation for flood mitigation and enabled to highlight opportunities that these measures may generate, as summarized in the following three points.

- Firstly, it is essential to move from a short-term to a long-term political vision to enable the uptake of NBS and avoid the paradox of a mismatch between long-term desired goals and short-term actions described by S. Sarabi et al. (2020), of which the Renaturation of the Po Area is an example. The RftR case in the NL demonstrates that a long-term vision and approach are key to tackling not only political barriers but also uncertainty-related, social and economic barriers, by allowing time to research, experiment, involve local communities to create consensus on NBS and provide long-term fundings, being in line with findings in the literature (S. Sarabi et al., 2020). Moreover, following the example of the NL, the adoption of integrated flood management measures in the PV can greatly contribute to NBS uptake by providing a supportive regulatory and institutional framework for their implementation, and can strengthen the pivotal multi-scale and multi-disciplinary collaborations between stakeholders already existing in the PV (Kumar et al., 2020; Ramírez-Agudelo et al., 2020; S. E. Sarabi et al., 2019).
- Secondly, knowledge and education around NBS for flood mitigation need to be fostered on a broader and integrated dimension to tackle uncertainty-related barriers in the PV. These barriers cause the misalignment between objectives and technical realization of NBS interventions (Kumar et al., 2020; S. E. Sarabi et al., 2019; Wickenberg et al., 2021). Lessons from the NL show that by enhancing experimentation and co-creation of knowledge, integrating local knowledge in the projects, fostering knowledge-sharing, and creating guidelines for NBS implementation, uncertainty-related barriers can be overcome thus enabling NBS uptake (Kumar et al., 2020; S. E. Sarabi et al., 2019; Wickenberg et al., 2021). For the PV, this means learning from completed small-scale projects as these processes have been already activated and applying them to a larger scale, as well as learning from international best practices as the NL did (Rijke et al., 2012; Zevenbergen et al., 2015).
- Finally, small-scale processes and international best practices can also provide the PV with the opportunity to learn how to engage with local communities when implementing a large-scale project, thus fostering participatory processes to a greater extent. This aspect was crucial in the successful implementation of NBS in the NL, and is key to reaching broad consensus, trust and

support from the communities involved in the projects, also contributing to preventing opposition and clashes on landownership and land use, as found by many researches (Kumar et al., 2020; S. E. Sarabi et al., 2019; Wickenberg et al., 2021).

The adoption of these lessons from the NL, the suitability of the NBS considered in this research (i.e. floodplain restoration, retention basins and ponds, afforestation and riparian river buffers) in the PV as well as the actual availability of space for these interventions, ultimately create the opportunity to implement these strategies in the PV to achieve both long-term and large-scale flood protection. Moreover, it is worth recalling that besides flood mitigation, NBS can provide the opportunity for the PV to achieve co-benefits for both the environment and society, contributing to restored habitat and biodiversity and providing space for recreational areas to increase human well-being, therefore being generally more adaptive and cost-effective than traditional grey solutions (Eisenberg & Polcher, 2019; Kumar et al., 2020; Pauliet et al., 2017). Finally, given their effectiveness and the multiple benefits associated with them, the implementation of large-scale NBS for flood mitigation may therefore be a successful strategy in countering the impact of climate change in PV, which together with land use change and urbanization sprawl is expected to experience increased frequency of high-impact floodings (Castellarin et al., 2010; Coppola et al., 2014; Dankers & Feyen, 2008; Zanchettin et al., 2008).

5.1. Recommendations

This research finally provides recommendations for policymakers and stakeholders planning and operating at the Po River basin level (namely AdbPo and AIPO) on key enablers to foster the large-scale implementation of NBS for flood mitigation in the PV.

First, since NBS produce benefits in the long term, policymakers must adopt a long-term vision and support long processes to align long-term planning with long-term objectives and overcome political barriers. Also, on one hand, this promotes knowledge building, long-term collaboration among stakeholders and long-term funding, thus contributing to dismantling uncertainty-related and economic barriers; on the other hand, it allows raising awareness and educating local communities, broadening social acceptance thus counteracting social barriers. Second, there is a need for integrated approaches. Integrated measures for flood management are key for the NBS to effectively mitigate floods at a large scale; there is also a need for integrated multi-scale and multi-disciplinary collaboration and knowledge-sharing, with a particular focus on local knowledge. This can contribute to tackling political and uncertainty-related barriers. Third, broad participative processes that actively involve local communities in the co-design and co-planning of solutions are of utmost importance to generate trust and prevent social opposition and clashes on landownership and land use, thus contributing to overcoming both social and spatial barriers.

Finally, due to the high socio-economic relevance of the PV for Italy, the increased frequency of catastrophic flood events that the PV is expected to face because of climate and land-use change and the large-scale long-term flood protection that NBS can provide, the recommendation for policymakers, AdbPo and AIPO to foster these flood mitigation strategies is to focus on three key-words: *long-term, integrated* and *participative*, as these are at the core of NBS principles (Eisenberg & Polcher, 2019; Kumar et al., 2020; Pauliet et al., 2017).

5.2. Limitations and future research

This study adopted a mixed-methods approach by combining both qualitative and quantitative methods to overcome the shortage of scientific data on the topic and deliver a comprehensive and exhaustive overview of barriers and enablers for large-scale NBS implementation for flood mitigation in the PV. Nevertheless, despite the provision of recommendations for the PV to foster these strategies, this study does not assess the effectiveness of NBS on flood mitigation in this territory. The spatial allocation aims to only illustrate the potential spatial availability of four kinds of NBS, thus further research is needed to assess where these interventions should be allocated to guarantee flood protection to the PV, for instance via hydrological modelling. Furthermore, results from the spatial allocation of NBS depend on the set of base maps used as input for the toolbox developed by Mubeen et al. (2021), however, it is possible to use other or additional base maps which were not included in this spatial analysis (e.g. railways, national parks, protected areas, etc.) to create finer suitability maps. Also, it has to be noticed that apart from floodplain restoration, retention basins and ponds, afforestation and riparian buffer strips, other NBS may be suitable for the PV. Therefore, further research should focus on detecting which NBS are the most suitable for the PV, also considering the impact that land allocation to NBS could have on the economy of the area. Similarly, although co-benefits were mentioned, this research did not investigate the kind of co-benefits that NBS could bring to the PV and to what extent, for which a cost-benefit analysis may be an object of future research. Lastly, although the barriers-enablers framework indicates that barriers can drive other barriers, these connections were not explicitly investigated during the interviews and literature review, although reported when mentioned.

5.3. Scientific and social relevance

The scientific relevance of this research lies in its contribution to filling the knowledge gap on the implementation of NBS as a flood mitigation strategy in PV. This topic is poorly studied, even though these strategies have been increasingly acknowledged as effective for flood mitigation, are cost-effective, and provide co-benefits compared to traditional grey solutions (Sahani et al., 2019). Furthermore, this research contributes to addressing the social challenge arising from catastrophic flooding in a relevant socio-economic area of Italy, the PV, which is expected to face an even greater flood risk due to the increased frequency of flooding caused by climate change, land-use change, and urbanization sprawl (García-Valdecasas Ojeda et al., 2022; Pedro-Monzonís et al., 2016; Romano & Zullo, 2016). The result of this research is therefore of social relevance, as it provides recommendations to policymakers and local authorities to encourage the implementation of NBS in PV to mitigate floods based on the lessons learnt from the NL, thereby decreasing the current and future impacts of flooding in the area. Overall, this research contributes to more sustainable flood management in the PV, fitting into the broader framework of Sustainable Development outlined in the 2030 Agenda.

6. Conclusion

This research provides insights into lessons learned from the NL to the large-scale implementation of NBS in the PV to mitigate floods. Results reveal that these measures are feasible in the PV and that to foster their uptake, long-term, integrated and participative actions must be undertaken. By learning from the NL, the PV can use NBS to achieve flood protection and co-benefits on the long-term and on a large scale, which is crucial in anticipation of the expected increase in catastrophic flooding due to climate change, land use and urbanisation.

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Appendix

Table 9 Boundary conditions for the allocation of NBS in the PV, encompassing floodplain restoration (FP), retention basins and ponds (R), afforestation (AFF) and riparian buffer strips (RB).

Boundary conditions	FP	R	AFF	RB
Slope	≤ 5 %	≤ 5 %	≤ 60 %	≤ 60 %
Distance from rivers	≤ 1 km	≤ 1 km	-	≤ 100 m
Distance from roads	≥ 50 m	≥ 50 m	≥ 50 m	≥ 50 m

Reclassification Aquifer type

AQUIF_CODE	AQUIF_NAME	Suitability
1	Highly productive porous aquifers	1
2	Low and moderately productive poro	0
3	Highly productive fissured aquifers (i	1
4	Low and moderately productive fissu	0
5	Locally aquiferous rocks, porous or fi	1
6	Practically non-aquiferous rocks, por	0
200	Inland water	0
300	Snow field / ice field	0

Reclassification land use CLC

GRID_CODE	CLC_CODE	FP	R	AFF/RB
10	141	1	1	1
11	142	1	1	1
12	211	1	1	1
13	212	1	1	1
14	213	1	1	1
15	221	1	1	1
16	222	1	1	1
17	223	1	1	1
18	231	1	1	1
19	241	1	1	1
20	242	1	1	1
21	243	1	1	1
22	244	1	1	1
23	311	1	1	0
24	312	1	1	0
25	313	1	1	0
26	321	1	1	0
27	322	1	1	0
28	323	1	1	0
29	324	1	1	0
30	331	1	1	0
31	332	1	1	0
32	333	1	1	1
33	334	1	1	1
35	411	1	1	0
36	412	1	1	0
37	421	1	1	0
38	422	1	1	0
39	423	1	1	0
40	511	0	0	0

Reclassification Land use ESA

Map code	Land Cover Class	FP	R
10	Tree cover	1	1
20	Shrubland	1	1
30	Grassland	1	1
40	Cropland	1	1
50	Built-up	0	0
60	Bare / sparse vegetation	1	1
70	Snow and Ice	0	0
80	Permanent water bodies	0	0
90	Herbaceous wetland	0	0
95	Mangroves	0	0
100	Moss and lichen	1	1

Figure 15 Toolbox used in ArcGIS Pro 3.0 for the creation of suitability maps per each NBS type. Provided by Mubeen et al. (2021).

Table 10 Flood impact for each region according to the HPH, MPH and LPH scenarios on the following categories: land, population, number of buildings, industries and services, and cultural heritage. The percentages refer to the regional values, for instance, the % of land in Piemonte affected by flood under an HPH scenario is 5.1% of the total land of Piemonte. Data retrieved from ISPRA (2021).

Scenario	HPH					MPH					LPH				
Region	**Land**	**Pop.**	**Build.**	**Ind. Serv.**	**Cult. Her.**	**Land**	**Pop.**	**Build.**	**Ind. Serv.**	**Cult. Her.**	**Land**	**Pop.**	**Build.**	**Ind. Serv.**	**Cult. Her.**
Piemonte	5.1%	1.5%	2.1%	1.8%	4.5%	8.3%	4.9%	5.8%	5.1%	9.3%	13.0%	16.0%	15.9%	16.1%	19.5%
Lombardia	7.9%	2.1%	2.4%	2.2%	5.3%	10.2%	4.4%	4.7%	4.5%	8.4%	20.3%	14.4%	17.0%	13.9%	21.8%
Emilia-Romagna	11.6%	9.9%	10.2%	9.1%	8.4%	45.6%	62.5%	59.0%	60.9%	57.1%	47.3%	69.4%	63.8%	68.6%	65.7%
Veneto	10.0%	8.7%	7.8%	9.3%	20.1%	13.3%	11.7%	10.8%	12.3%	21.6%	32.2%	32.1%	30.8%	32.3%	34.0%
Friuli-Venezia Giulia	9.6%	5.1%	5.3%	7.3%	11.7%	14.6%	9.9%	10.9%	12.5%	16.5%	21.5%	19.9%	22.0%	24.4%	27.7%

Table 11 Overview of some of the major flood events that occurred in the PV regions (excluding Lombardia, for which no data was available in scientific literature) since 1951. The events are briefly described and underlying causes are listed.

Region	**Area**	**Years**	**Description**	**Causes**	Sources
Piemonte	Alessandria, Cuneo, Torino and Asti Provinces	1994	The flood was caused by the overflow of the Tanaro and Po Rivers and their affluents. More than 300 mm of precipitation in 36 hours caused the tributaries to reach their maximum discharge levels simultaneously, leading to a peak discharge of 3,250 m^3/s. This destructive flood affected nearly 130 cities causing extensive damage to the economy of the region, 70 lives were lost and more than 2,000 people were evacuated.	- Exceptional rainfall; - Channelization of the Tanaro River which caused irregular and narrow river flow; - Urbanization along the river banks and in the riverbed; - Interference of infrastructures (e.g. roads and railways) with flow dynamics; - Lack of maintenance of the natural drainage system that contributed to the obstruction of waterways and consequent overflows;	(Buzzi et al., 1998; Luino, 2015)

	Cuneo Province	2008	The flood was caused by the overflow of the Maira and Grana-Mellea Rivers and flooded more than 10 km^2 of land including urban areas. It caused 4 human losses and several damages to properties.	- Wet spring followed by heavy and continuous rainfall; - Infrastructures caused the narrowing of the river; - Interference of an artificial channel running along the river with the water flow;	(Audisio & Turconi, 2011)
	Alessandria Province	2019	A high-magnitude flood with a 500-year return time was caused by the Orba River and led to the modification of local geomorphology and severe damage to infrastructures and crops. The peak discharge reached nearly 2,800 m^3/s and an area of 17.65 km^2 flooded.	- Intense prolonged rainfall followed by a thunderstorm; - Interference of infrastructures on flood propagation; - Levee failures and unrepaired breaches; - Levee overtopping; - Major channel alterations due to the extraction of sediments and channelization; - Conversion of areas adjacent to the floodplain into cultivated areas;	(Mandarino et al., 2021)
Emilia-Romagna	One-third of plains	1996	200 mm of rainfall in two days caused one-third of the region to be flooded due to insufficient capacity of the drainage networks.	- Intense rainfall; - Inadequate local artificial drainage system;	(Pistocchi et al., 2015)
	Bologna, Modena, Ravenna, Forlì, Cesena Provinces	2023	Two major rainfall events affected the region over less than 20 days, reaching 450 mm of rain cumulatively. 21 rivers overflowed, flooding 37 municipalities and causing more than 15000 people to be evacuated and 14 victims.	- Two consecutive high-magnitude rainfall events over a short time; - River overflow;	(Ansa, 2023; ISPRA, 2023; *Maltempo Emilia-Romagna: Continua L'impegno Del Servizio Nazionale Nei Territori Colpiti*, n.d.)
Veneto	Polesine	1951	The flood in Polesine, a downstream area of the PV, was caused by prolonged and heavy rain over the whole PV, with an average precipitation of 214 mm in 7 days. The simultaneous formation of waves in upstream tributaries triggered overflow of the Po River and three bank failures, leading to 8 billion m^3	- Prolonged heavy rainfall; - Geomorphological characteristics: lowland flat area affected by anthropological and natural subsidence located in the	(ISPRA, 2021; Masoero et al., 2013; Viero et al., 2019)

			of water to flood an area of nearly 1000 km^2. During this event, the peak discharge in the downstream part of Po River reached 9500-10100 m^3/s. The flood caused more than 100 deaths, around 200000 evacuees and homeless and significant damages to infrastructures and crops, severely impacting the regional economy. This is considered one of the most catastrophic flood events in Italy and was used as a benchmark for the implementation of new flood mitigation strategies in the whole PV, which mainly entailed the rise of embarkments. This area is still significantly threatened by residual flood risk, especially for floods with a 200-year return period.	downstream part of the Po River and confined by the Adriatic Sea; - Artificial barriers in the floodplain;	
Friuli-Venezia Giulia	Latisana	1966	The Tagliamento River reached a peak discharge greater than 4000 m^3/s. In the following years, the Tagliamento River overflowed regularly in regions upstream of Latisana, due to branches confinement and narrowed floodplain, which led to higher flood frequency and magnitude.	- Overflow caused by co-occurring causes, namely flood upstream and tidal backwater from the Adriatic Sea; - Heavy anthropological modification of the river system (e.g. dikes, drainage of wetlands and conversion of pastures into cropland) which exacerbated the occurrence of flood events in downstream areas; - Natural processes: geologic and climatic conditions are shifting the transition of the riverbed from braiding to meandering downstream, increasing flood risk in these areas; - Torrential regime of the Tagliamento River due to rainfall pattern resulting in flash floods;	(Spaliviero, 2003)

Table 12a Description of completed NBS interventions aimed at flood reduction in the PV and main NBS strategies used.

Brief description of completed NBS cases in the PV for flood mitigation	**Sources**
Restoration of the floodplain of the Montone River at the confluence with the Rabbi Stream as part of the regional project "Clean Rivers" in the Municipalities of Forlì and Castrocaro in Emilia-Romagna. The project encompassed bank removal and reallocation inland.	Restoring European Rivers' RiverWiki (n.d.)
Removal of internal embarkments and floodplain lowering over 9 hectares along the Montone River as part of the "Clean Rivers" project at San Tomè, in Emilia-Romagna.	
Constructed wetlands to buffer flood peaks improve water quality and restore riparian trees in Gorla Maggiore, Lombardia.	*GeoIKP* (n.d.)
A flood retention basin for the Lura River was constructed in Como, Lombardia, with 340,000 m^3 of storage volume on a 20-hectare area. River bank renaturation and stabilization by riparian afforestation and vegetated dikes.	*Flood Retention Basins of Lura River, Como Province (2022); GeoIKP* (n.d.)
Plantation of rooted vegetation on embankment slopes downstream of the Panaro River, Emilia-Romagna, to mitigate the erosive action of water flow and improve soil resilience to reduce the risk of embankment and riverbank collapse during flood events.	*GeoIKP* (n.d.)
Creation of a water storage area of 700 m and floodplain vegetation to reduce water flooding and pollution in San Giovanni in Persiceto, Emilia-Romagna.	
A water retention basin with a 2,500 m^3 capacity was built in Giavenale di Schio, Veneto, and surrounded by a strip of vegetation.	

Table 12b Summary of the information available and retrieved from every case examined in the PV about NBS interventions for flood mitigation implemented. Barriers and enablers refer to the five categories identified as political (P), uncertainty-related (U), social (S), economic (E) and spatial (SP). The grey boxes indicate what information was available for every project examined.

NBS projects	**Barriers**					**Enablers**				
In the PV	P	U	S	E	SP	P	U	S	E	SP
Restoration of the floodplain on the Montone River										

Floodplain restoration on the Montone River at San Tomè										■
Wetlands in Gorla Maggiore						■		■	■	
Flood retention basin of Lura River		■				■	■	■	■	■
Revegetation of the Panaro River banks		■		■				■		
Flood measures in San Giovanni in Persiceto										
Water retention basin in Giavenale di Schio		■				■	■	■	■	

Table 13a Overview of completed NBS interventions that have enabled flood reduction in the Netherlands and different NBS strategies that have been used.

Brief description of completed NBS cases in the NL for flood mitigation	**Sources**
Reconstruction of the Bakenhof Dyke to widen the floodplain by 200 meters, creation of a secondary channel and revegetation of the floodplain to increase channel capacity.	Restoring European Rivers' RiverWiki (n.d.)
Stream restoration of the Beekherstel Buurserbeek by making the stream wider and shallower to improve flow dynamics.	
River bed widening and levee reprofiling of the Rijkelse Bemden	
Afforestation and re-design of the stream Koffiegoot through the creation of pools, heathland and grassland to retain more water.	
Excavation upstream of the Ijssel River floodplain, in Keizers-en Stobbenwaarden and Olsterwaarden, and the creation of side gullies to allow more room for the river and increased drainage.	
Depoldering of the Noordwaard in Altena by dike removal, which allows 44.5 km2 of land to be flooded during high tide. It is part of the RftR project.	*GeoIKP* (n.d.)
Dikes on the river Waal were reallocated 350 meters inland in Lent, a village in Nijmegen municipality, and a new river channel was built next to the Waal, leading to a 35 cm river water height reduction. This project is part of the RftR programme.	

A water storage area with 187.000 m3 of capacity was built between the cities of Hengelo and Enschede to protect them from floods.	
The recovery of the Meuse River led to the broadening of its stream and the lowering of the floodplain in a 50 km-long area along the Dutch-Belgian border, between Maastricht and Maaseik. The intervention also included gravel augmentation to restore deposition/erosion dynamics.	*River Meuse project* (2022)
As part of the RftR, the River Ijsseldelta was given more space by deepening the summer bed of the Jissel over 8 km and by building a 7 km long water channel between the Ijssel and the Drontermeer.	Ministerie van Infrastructuur en Waterstaat (2022)

Table 13b Summary of the information available and retrieved from every case examined about NBS interventions implemented in the PV and in the respectively. Barriers and enablers refer to the five categories identified as political (P), uncertainty-related (U), social (S), economic (E) and spatial (SP). The grey boxes indicate what information was available for every project examined.

NBS projects	**Barriers**					**Enablers**				
In the Netherlands	P	U	S	E	SP	P	U	S	E	SP
Bankenhof Dyke										
Stream restoration of the Beekherstel Buurserbeek										
Rijkelse Bemden widening and ban reprofiling										
Re-design of the Beekherstel Koffiegoot										
Excavation of the Ijssel river floodplain and gullies										
Depoldering of the Noordwaard					■	■		■	■	■
Room for the River Waal						■	■	■	■	
Water storage area between Enschede and Hengelo						■		■		■
Recovery of the River Meuse								■		

Room for the River Ijsseldelta										

Appendix A

Semi-structured interview scheme

General questions on flood risk in the PV and NBS:

a. Can you briefly describe what is the current flood risk situation and flood impacts (e.g. percentage of land/people at risk, economic losses...) in the PP?

b. What are the main causes of destructive floods in the PV?

c. What flood mitigation strategies have been implemented and what were the main reasons behind these choices?

d. What is the state of the art of NBS for flood mitigation in the PV?

Questions on barriers and enabling factors for NBS implementation

a. Which barriers hinder the implementation of these measures?

b. Which political/regulatory factors are currently in place to favour NBS implementation?

c. Are there uncertainties regarding the implementation of NBS? Which ones?

d. Which stakeholders should be involved in the process and how?

e. Are there funding opportunities and which ones?

f. What methods are adopted to overcome social barriers (e.g. to increase acceptance of NBS)?

g. How to deal with spatial constraints in PV?

h. Are there already opportunities to promote NBS implementation in PV (or more generally in Italy)? If yes, which ones?