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Nature-based solutions for flood-management in Asia and the Pacific

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Abstract

Countries in Asia and the Pacific face a heightened risk of flooding as disasters increase worldwide due to climate change. Yet these countries often lack the infrastructure necessary to prepare for and respond to floods effectively. When flood protection measures exist, they generally rely only on grey, hard-engineered infrastructure, which has been increasingly challenged in recent years. Nature-based solutions (NbS) offer a new approach for flood management, with several co-benefits beyond the reduction of risks. This approach has gained recognition from policy makers in the region, but they are confronted with a number of challenges, including the lack of a clear, common definition and guidelines, as well as financing issues. The growing imperatives of climate adaptation call for complementary, innovative and forward-looking solutions, such as a combined approach incorporating both NbS and grey infrastructure.

JEL classification: Q54, Q57, O53, O20

Keywords: Nature-based solutions, flood management, flood infrastructure, disasters, Asia and the Pacific

Résumé

Alors que les catastrophes augmentent dans le monde entier en raison du changement climatique, les pays d’Asie et du Pacifique font face à un risque accru d’inondations. Or ces pays manquent souvent des infrastructures nécessaires pour s’y préparer et y répondre efficacement. Là où des mesures de protection contre les inondations existent, elles reposent le plus souvent uniquement sur des infrastructures grises ou lourdes qui sont de plus en plus contestées. Les solutions fondées sur la nature (SFN) proposent une nouvelle approche de la gestion des inondations, dont les co-bénéfices vont au-delà de la réduction des risques. Les décideurs de la région l’ont bien compris, mais ils font face à plusieurs défis, notamment l’absence d’une définition claire et commune et de lignes directrices, ainsi que des problèmes de financement. L’impératif croissant de l’adaptation climatique exige une combinaison de solutions complémentaires, innovantes et tournées vers l’avenir, telles qu’une approche intégrant à la fois les SFN et les infrastructures grises.

Classification JEL : Q54, Q57, O53, O20

Mots clés : Solutions fondées sur la nature, gestion des inondations, infrastructures contre les inondations, catastrophes, Asie et Pacifique.

Foreword

Natural hazards are becoming more frequent and severe. While this trend is a worldwide phenomenon, Asia and the Pacific is particularly severely affected. The region faces a variety of disasters, of which floods are among the most frequent – occurring as a result of tropical cyclones, extreme rainfall including greater-than-expected monsoon rains, sea-level rise and river overflow.

Developing resilience against floods must be a key policy priority for governments of the region. While efforts have historically been based on physical infrastructure solutions, nature-based solutions (NbS) have recently gained in popularity. Adding NbS to the flood risk management and climate adaptation mix would not only bolster efforts in the area of disaster risk reduction, but also provide benefits associated with restored environmental health and greater biodiversity.

While policy makers in Asia and the Pacific are already attentive to this approach, there is ample room for improvement. This paper examines the policy considerations needed for the NbS approach to reach its full potential in the region, including clear evidence-based guidelines to help policy makers develop disaster management plans. This paper is produced with the financial support of the government of Japan.

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1 Introduction

Across the world, the risks from natural hazards such as heat waves, floods and droughts are increasing, causing greater socio-economic and health impacts for society. Countries in Dynamic Asia and the Pacific[1] are particularly prone to these risks. This trend is driven by climate change, nature loss and rising exposures and vulnerabilities. Particularly, the interplay between climate change and nature loss is of growing concern: Climate stress creates a range of pressures on natural areas, which are undermining the functionality of ecosystems and leading to a decline of biodiversity (Intergovernmental Panel on Climate Change (IPCC), 2023[1]). This aggravates the impact of other environmental pressures such as pollution, land-use and deforestation: Globally, 75% of land is now degraded, and at least 20% of land-based species are estimated to have been lost since 1900 (CISL, 2020[2]). Although up to USD 143 billion of finance flows toward biodiversity conservation annually, conservation efforts have not been able to halt global biodiversity loss, which is expected to increase (CISL, 2020[2]; EEA, 2021[3]). The decline of ecosystem services, i.e. the benefits derived from nature, will cause an estimated USD 10 trillion of economic losses by 2050; at the same time, more than 50% of global gross domestic product (GDP) is moderately or highly dependent on nature (CISL, 2020[2]).

In order to tackle the underlying risk drivers and frame risk management as an investment opportunity, risk management needs to take a more integrated, holistic and forward-looking approach. One area that promises a range of co-benefits in dealing with increased climate risks and nature loss are nature-based solutions (NbS). These are different to traditional hard-engineering (grey) solutions, such as the building of seawalls to contain rising waters. NbS focus more sharply on solutions that nature itself can provide and are defined as "measures that protect, sustainably manage or restore nature, with the goal of maintaining or enhancing ecosystem services to address a variety of social, environmental and economic challenges" (OECD, 2020[4]). NbS are increasingly seen as a critical means of adapting to climate change, offering not only social and environmental benefits but also economic gains, as well as emission reduction opportunities in the form of carbon sinks.[2]

Nature-based solutions can play a key role and deliver significant co-benefits in flood risk management. This is particularly pressing given the increase in flooding due to heavy rainfall and rising seas and rivers caused by climate change. About 40% of the world's population lives within 100 km of a coastline, and more than 600 million people live in coastal areas less than 10 metres above sea level (NASA, 2023[5]; OECD, 2021[6]; Kirezci et al., 2020[7]). According to the IPCC 6th Assessment Report (Intergovernmental Panel on Climate Change (IPCC), 2023[1]) flood risk is expected to increase for many regions under

[1] Dynamic Asia refers to the member countries of the Association of Southeast Asian Nations (ASEAN), member countries of the South Asian Association for Regional Co-operation (SAARC), Central Asia, China, and Mongolia. The Pacific includes Pacific Island countries with available data.

[2] Recent discussions about natural capital and investing in nature show the growing interest of academia and policy makers in NbS, including within the European Union, in the European Green Deal or, more recently, in the EU Sustainable Finance Taxonomy (Kirsop-Taylor and Russel, 2022[37]; McQuaid et al., 2021[156]). There is also a growing focus on biodiversity and financial stability, particularly in the context of forests. The London School of Economics forestLAB research programme focuses, for instance, on designing world-class models for integrated, climate-smart landscape management and exploring mechanisms to monetise ecosystem services, with an initial focus on equatorial Africa.

different climate scenarios, with steep increases under 1°C of warming. This will have direct and indirect impacts on communities and economies, including through disruption of supply chains and infrastructure. For example, currently 23% of the world's power generation capacity, 26% of international port outflows, and 18% of international airport seats are currently at risk of flooding and these percentages are projected to rise to 41%, 52% and 37% respectively under a 2°C warming scenario (Marsh McLennan, 2023[8]).

Changing risk patterns are straining the capacity of grey infrastructure to manage risk. This is particularly the case in Dynamic Asia and the Pacific, where investment in maintaining the quality of existing flood control infrastructure tends to have less priority, and it is relying solely upon the preventive function of grey infrastructure in the face of changing climatic and hydrological conditions is unrealistic. Moreover, rapid urbanisation and changes in land use rarely come with infrastructure that is adequate to deal with flooding. As natural floodplains and wetlands are converted into urban areas, the risk of flooding increases.

Nature-based solutions can help, such as natural and artificial wetlands can help to mitigate the problem, as can increasing prevention or adaptation capacity. For example, small-scale NbS may involve planting gardens and grass verges along streets. A study found that approximately 1.3 million trees have the potential to capture 7 billion cubic metres of rainwater per year (Jha, Bloch and Lamond, 2012[9]). This could significantly decrease the burden on stormwater drainage systems, ultimately preventing flooding. The implementation of green and blue infrastructure and establishment of green spaces is therefore crucial. Common practices include constructing green roofs, establishing community woodlands, landscaping around buildings and creating urban parks and gardens. On a larger scale of green infrastructure as NbS may include an interconnected network of wetland areas that are connected to natural wetlands. Green infrastructure can also enhance ground water storage by improving soil infiltration.

In Dynamic Asia and the Pacific, the NbS approach has gained recognition from both national governments and development partners, and a number of projects that incorporate NbS have been carried out to address different types of flooding. However, the majority of these projects are still at an early stage or have only been tested by limited number of cases.

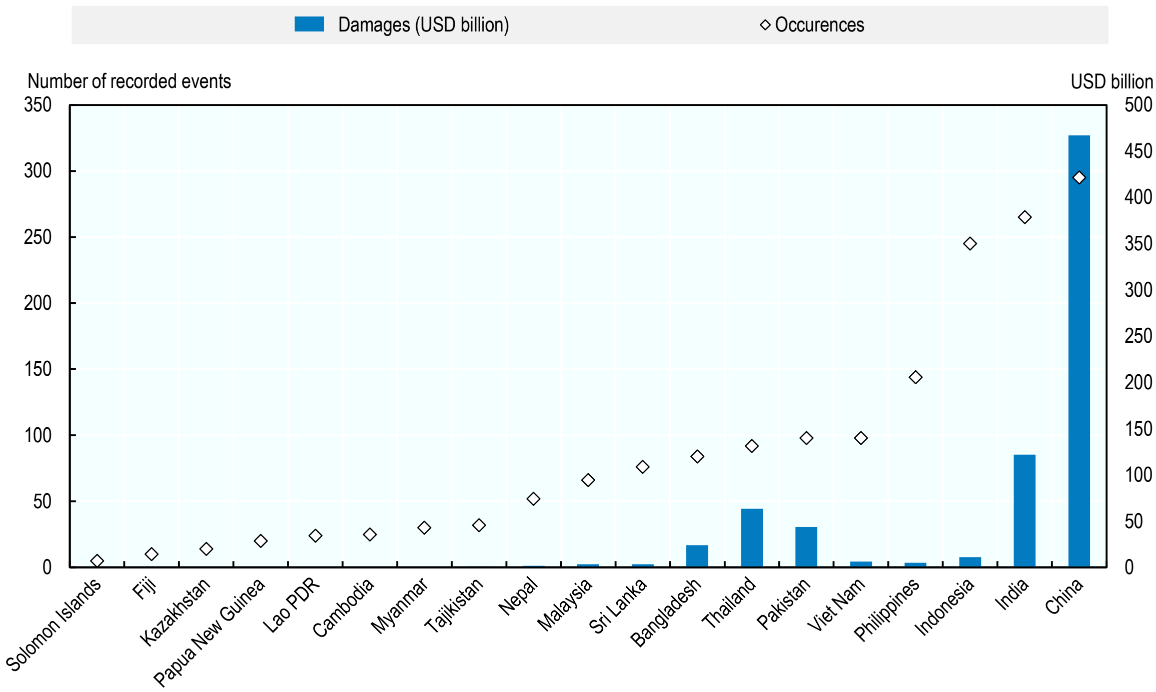
The economic, social and environmental conditions of Dynamic Asia and the Pacific, and the specific flood risks faced by countries in the region, present unique challenges. The growing challenges of climate adaptation call for complementary, innovative, and forward-looking solutions, such as a combined approach incorporating both NbS and grey infrastructure. Such solutions may offer better results in terms of flood protection, biodiversity and ecosystem protection and harness wider socio-economic benefits.

This study begins by discussing challenges related to grey infrastructure for flood protection in Dynamic Asia and the Pacific under the changing climate and landscape conditions. It then examines NbS as a complementary and innovative approach to tackle flooding, as well as issues related to the adoption of nature-based solutions in the region. Examples of the use of NbS for flood risk management in OECD countries are presented, followed by case studies from Asian and Pacific Island countries. These case studies help to illustrate the country-specific challenges of integrating NbS to manage flooding in the region. Finally, the paper offers recommendations for integrating NbS as part of flood risk management while accounting for the economic, social and environmental conditions in Dynamic Asia and the Pacific.

2 Growing flood risk and flood control grey infrastructure in Dynamic Asia and the Pacific

Floods represent the most frequent type of disaster in Dynamic Asia and the Pacific, accounting for 41% of the 5 216 recorded disasters in the region between 1980 and 2022 (CRED, 2023[10]; OECD/ADBI/Mekong Institute, 2020[11]). Floods in the region affected around 80 million people a year on average over the same period, occurring most frequently in China, India, Indonesia and the Philippines (Figure 1). In terms of damage, China, India, Thailand and Pakistan suffered the most destruction from floods. For instance, a major flood in Thailand in 2011 caused damage equivalent to around 11% of the country's GDP. More recently, Pakistan suffered damage equivalent to about 4% of its GDP from a flood in 2022. Among countries in Central Asia, Tajikistan suffers the most from flooding with a total of 32 recorded flood events between 1980 and 2022 (Figure 1). The country's most devastating flood occurred in 1992, with damage amounting to roughly 14% of its GDP. In the Pacific region, storms are the most frequent disasters, followed by floods, which made up around 16% of the disaster events affecting the region's 13 countries between 1980 and 2022 (CRED, 2023[10]). Fiji, Papua New Guinea and the Solomon Islands are the Pacific Island countries most frequently hit by floods, and such extreme events can have particularly devastating impacts on the economies of these small island states. For instance, a major flood in Papua New Guinea in 1999 caused damage equivalent to around 12% of the country's GDP, while major flooding in Fiji in 2012 cost the country 18% of its GDP.

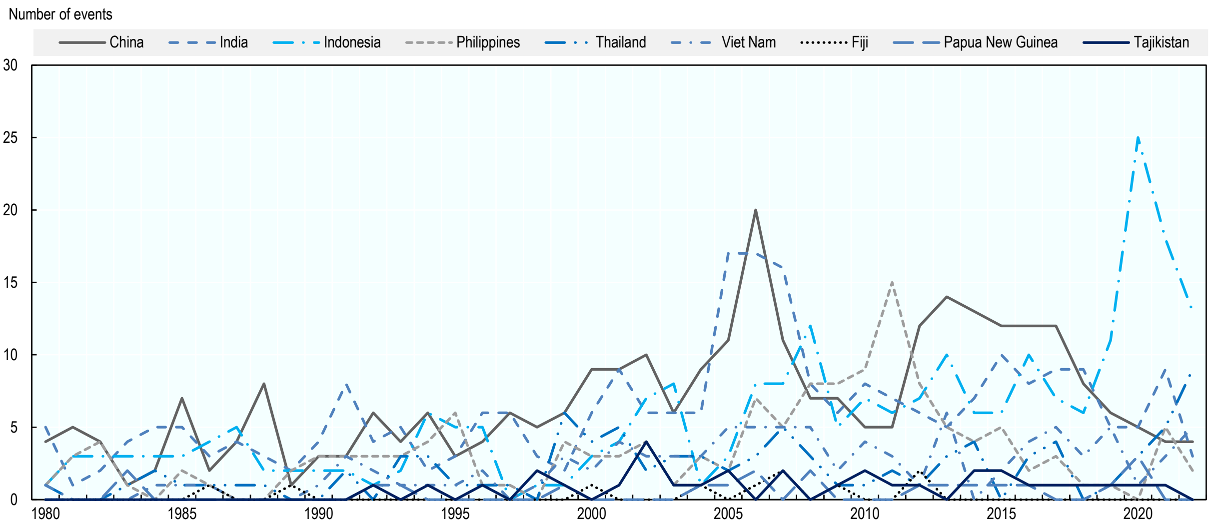
Figure 1. Flood events and damage in Dynamic Asia and the Pacific, 1980-2022



Source: (CRED, 2023[10]).

With sea-level rise and land-use change, floodplains can expand to areas with high population density, exposing more people to the risk of flooding. Coastal cities in particular are increasingly faced with surge-induced flooding in the event of sea-level rise. Bangkok; Ho Chi Minh City; Shenzhen, China; and Manila are among the world's cities most vulnerable to sea-level rise, according to the 2050 Climate Change Index. With climate change intensifying annual rainfall, poor urban planning and inadequate infrastructure may worsen flooding in the already sinking cities. Indeed, the annual incidence of floods has generally trended upward between 1980-2022 in some Emerging Asian countries (Figure 2).

Figure 2. Recorded flood events in selected countries in Dynamic Asia and the Pacific, 1980-2022



Source: (CRED, 2023[10]).

Due to the increasing risk of floods and the growing number of people vulnerable to them, more interventions will be needed to protect people and property. Grey infrastructure such as drainage systems, dams, dikes and levees still plays an important role in flood risk management, but climate change and rapid urbanisation may challenge this approach. Existing infrastructure is often insufficiently maintained, and its capacity is overwhelmed by the growing population and economy. Therefore, it does not function as it had been expected to at the time of construction. This challenge can be illustrated by examples from the region.

- The city of Bogor, **Indonesia** was hit by a flash flood in 2017 caused by heavy rainfall. Although rainfall in Bogor was not the highest on record, heavy rainfall in upstream areas had increased the flood risk. The situation was made worse by inadequate urban drainage infrastructure, which relied on former irrigation channels. Field observations revealed that some of these channels had been converted into built-up areas. Such loss of water retention areas exacerbates the risk of flash flooding (Ramdhan et al., 2018[12]).
- In **Thailand**, the Rasi Salai irrigation dam, on the Mun river in the northeast, stands 17 meters tall and has substantial reservoir space. However, environmental assessments or public hearings were not well-conducted prior to the dam's completion in 1994. When the dam was brought online, water flooded local agricultural areas and inundated seasonally flooded forests, which serve as a vital source of food and well-being for local people. This flooding led to the displacement of more than 3 000 families from their homes and farms (Yamsiri, 2014[13]).
- In **Cambodia**, upstream dams were found to have an insignificant impact on the extent of flooding in the lowlands, with an average decrease in annual flooded area of just 3-5% from 1996 to 2000 (MRC, 2012[14]). Dam failure, although rare, can also cause flooding across national boundaries. The collapse of the Xe Pian Xe Namnoy hydropower dam in Lao PDR in 2018 resulted in a devastating flash flood in Cambodia's northeastern provinces, with water levels rising to 12 meters, causing the displacement and evacuation of thousands of people in Cambodia (Baird, 2020[15]; Phy et al., 2022[16]).
- In **Lao PDR**, the Houy Longkong floodgate, located 120 metres from the Mekong River, is unable to serve its multiple purposes, which include flood protection, water supply for agriculture, and urban drainage. The southern flood gate and canal system is highly susceptible to flooding due to increased rainfall in its catchment area and higher water levels in the Mekong River caused by climate change (ADB, 2016[17]). In another location, inadequate waste and stormwater drainage systems make the Savanxay Market highly exposed to flooding from increased rainfall and from the overflow of the Mekong River due to climate change (ADB, 2016[17]).
- A major flood that struck **Bangladesh** in 1998 left around two-thirds of the country under water for more than two months and caused the most damage of all flood events in the country from 1980-2022 (CRED, 2023[10]). Bangladesh is prone to flooding: 21% of the country's area is flooded annually on average (Dewan, Nishigaki and Komatsu, 2003[18]). Natural factors that contribute to flooding include heavy rainfall over the catchment areas of Bangladesh's major rivers, snowmelt in the Himalayas and geophysical instabilities in the northern regions (Dewan, Nishigaki and Komatsu, 2003[18]). The capital city, Dhaka, which is surrounded by rivers, was severely inundated during the 1998 flood due to hydraulic leaks, such as buried sewerage pipes, breached and incomplete floodwalls and ungated culverts (Faisal, Kabir and Nishat, 2003[19]). Moreover, pumping stations lacked sufficient capacity and the city's drainage system and retention ponds were in poor condition.
- In **Sri Lanka**, a rapid decline in urban vegetation in the capital city, Colombo, has increased the risk of water accumulation for extended periods. The city's old and inadequate drainage infrastructure is insufficient to handle water surges and worsens risk of urban flooding (Mukherjee et al., 2022[20]).

- In **Pakistan**, the flood control infrastructure dates back to the 1850s, with the oldest structures in poor condition due to lack of proper maintenance (Aslam, 2018[21]). Other issues stem from improper planning and design of flood control infrastructure. The design of embankments has not changed for decades, and the standard operating procedures for dealing with floods at dams, barrages, bridges and other infrastructure are not optimised to minimise damage from floods (Aslam, 2018[21]). Water storage reservoirs are effective in reducing short-term floods, but their effectiveness decreases during significant floods. This may be because the existing reservoirs are mainly designed for irrigation and hydropower generation, while flood control is a secondary concern. In addition, the storage capacity of reservoirs is decreasing over time due to sedimentation and is now at a very low level of capacity by international standards, making flood control all the more challenging.
- In **Tajikistan**, the construction of irrigation channels, river embankments, bridges and dams mostly took place during the Soviet era, i.e. prior to 1991. The deteriorating state of this infrastructure heightens the vulnerability of the population to extreme weather events and flood risks.
- The **Pacific Island countries** still have a long way to go to achieve effective flood risk management. For example, Fiji and Samoa still tend to prioritise structural works to limit overflow of water, such as river dredging and levee construction (Yeo et al., 2017[22]). While modifying flood behaviour can effectively reduce flood risk, these interventions should build on comprehensive cost-benefit, environmental and social impact assessments. However, evidence suggests dredging and levee projects are often made without a prior assessment of their economic viability or their social and environmental impacts (Yeo et al., 2017[22]). Nonetheless, there has been a gradual adoption of robust processes to evaluate the benefits of such flood modification measures before their implementation.

The use of grey infrastructure is still most prevalent (Dhakal and Chevalier, 2017[23]; Qiao, Kristoffersson and Randrup, 2018[24]) and remains important in the region. However, these examples show the importance of strengthening the design, operation, maintenance and overall management of grey infrastructure to protect against flood risks in the region (OECD, 2018[25]). To achieve this, sufficient well-planned investment in flood protection infrastructure is essential. Given the changing environment, the limited amount of budget, and sense of urgency, policy makers should give NbS serious consideration. The benefits and challenges of using NbS for flood control, and other policy considerations to facilitate the adoption of NbS will be explored in the remaining chapters.

3 The benefits of nature-based solutions

Nature-based solutions offer an alternative or complementary approaches to grey engineering infrastructure such as drainage channels or flood walls, which face different challenges in mitigating risks compared to NbS (Table 1). NbS aimed at protecting or restoring natural wetlands, restoring degraded farmland and floodplains, or revegetating embankments have been implemented to reduce flood risks while creating co-benefits, including carbon sequestration (Filoso et al., 2017[26]). In urban contexts, rain gardens, green roofs, permeable pavements or green and blue lanes have been used not only to manage stormwater runoff but also to improve air and water quality and biodiversity (Lee et al., 2021[27]). In coastal contexts, reefs, sand dunes and mangrove forests help to reduce the impacts of storm surges and sea-level rise, while at the same time providing leisure and economic opportunities in tourism sector (OECD, 2021[6]). NbS can also improve health and well-being (Kolokotsa et al., 2020[28]), and support heat mitigation efforts (Cortinovis et al., 2022[29]).

Table 1. Comparison between grey infrastructure and NbS in flood risk management

Characteristics	NbS	Grey infrastructure
Time scale	Takes longer for the benefits to materialise	Benefits are immediate after construction
Spatial scale	Typically executed on a larger scale to be effective, encompassing multiple jurisdictions	Typically implemented within individual jurisdictions
Performance reliability	Uncertain performance due to complexity of natural systems	Performance is more predictable
Flexibility	Adaptable to changing environmental conditions as they are part of the natural landscape	More rigid and with limited adaptability as it typically provides a fixed solution for flood management
Sustainability	More sustainable as it involves the restoration of natural ecosystems	Can have negative impacts on the environment, e.g. increased erosion, altered hydrology and destruction of natural habitat, and requires significant maintenance and upgrades over time
Multifunctionality	Provides multiple benefits beyond flood risk reduction	Often has a more singular focus on reducing flood risk and rarely provides additional benefits
Quantification of benefits	Co-benefits are difficult to quantify, e.g. human health and livelihoods, food and energy security, biodiversity	Benefits are easy to quantify, e.g. prevention of damage to assets
Community engagement	Design, implementation, and maintenance involve local communities, hence promote community ownership and resilience	Designed and implemented by external engineers and experts, hence limited community engagement and lack of local ownership

Source: Authors adapted from (OECD, 2020[4]).

In recent decades, nature-based solutions have received significant attention from the research community (Ruangpan et al., 2020[30]). Policy makers have shown interest in NbS, as in the EU Adaptation Strategy (European Commission, (2015[31]; 2020[32]; 2021[33]) and (Frantzeskaki et al., 2020[34]). So have governments (Alexander, Mckinley and Ballinger, 2019[35]) and industry, with the private sector in G20 countries investing USD 14 billion annually in NbS (UNEP, 2022[36]). However, investment levels remain low despite growing understanding of the role of nature and the importance of functioning ecosystems.[3] Translating NbS into policy and action remains a challenge. Kirsop-Taylor and Russel (2022[37]) have highlighted the key role of public environmental agencies in knowledge transfer for the translation of evidence on NbS into policy. This is necessary to remove institutional and policy barriers to implementation (Cohn et al., 2021[38]).

Despite increasing evidence about the wider role that NbS can play in the fight against climate change, there is room to promote its implementation for flood risk reduction (Mehryar and Surminski, 2020[39]). Griscom et al. (2017[40]) estimate that NbS could account for around 30% of the cost-effective mitigation measures needed by 2030 to keep the increase in global mean temperature below 2°C above the pre-industrial level. More than two-thirds of the signatories to the Paris Agreement on climate change mention NbS in their Nationally Determined Contributions (NDCs) to help meet their mitigation or adaptation targets (Nature Based Solutions, 2022[41]; Nature-based Solutions Initiative, 2018[42]).

Studies estimate that NbS implemented in all ecosystems could reduce emissions by at least 5 GtCO2e (gigatonnes of carbon dioxide equivalent) per year by 2030, and by at least 10 GtCO2e per year by 2050. About 62% of this contribution is projected to come from NbS in forests, 24% in grasslands and croplands, 10% in peatlands and 4% in coastal and marine ecosystems (UNEP and International Union for Conservation of Nature, 2021[43]; Griscom et al., 2017[40]; Girardin et al., 2021[44]; McKinsey & Company, 2021[45]; Roe et al., 2019[46]). Many studies have specifically addressed NbS for flood risk reduction, for example in Germany (Brillinger et al., 2020[47]), in the United Kingdom (Huq and Stubbings, 2015[48]), in China (Kong et al., 2017[49]) and in France (Versini et al., 2018[50]).

In the context of water management, nature-based solutions can help to restore natural water flow regimes (Fletcher et al., 2013). These solutions are generally more adaptive than conventional solutions (Faivre et al., 2018[51]) and offer opportunities for positive economic and social changes such as improved water and food security, health and well-being, clean water and sanitation, and improved biodiversity (Cohen-Shacham et al., 2019[52]; Debele et al., 2019[53]; Jerzy et al., 2020[54]). The scale of NbS for flood risk reduction can be large or small. Large-scale measures, such as reforestation or floodplain restoration, are implemented at a regional scale in river basins and cut across different ecosystems, while small-scale measures, such as rainwater harvesting, are implemented on a localised (urban or rural) scale (Ruangpan et al., 2020[30]).

Of particular interest in the context of flood management is the implementation of NbS in forests and wetlands. Forests store up to 65% of the world's terrestrial organic carbon and play an important role in managing the impacts of climate change (Reichstein and Carvalhais, 2019[55]). More than 1.6 billion people depend on forests for subsistence, employment and income generation, and the sector contributes roughly 1% to global GDP, although the share is significantly higher in many low-income developing countries (Campos Arce, 2019[56]). As climate change increasingly threatens the provision of a range of ecosystem services from the world's forests – including wood and non-timber products, protection against natural hazards, nutrient cycling, water purification and recreation – protecting and restoring forest landscapes has come into greater focus as a key adaptation strategy. According to Reguero et al. (2019[57]) a reduction of coral reef heights by one meter would cause a 62% rise in the number of people at risk of coastal flooding, along with a 90% rise in assets at risk, leading to an estimated increase in annual damages of USD 5.3 billion (Reguero et al., 2019[57]), as reported in (Marsh McLennan, 2023[8]). A report by the Global Commission on Adaptation (GCA, 2019[58]) finds that mangrove forests protect 18 million people from coastal flooding and contribute more than USD 80 billion per year in avoided losses. Mangroves also contribute USD 40-50 billion per year in non-market benefits associated with fisheries, forests and

[3] For example, the EC Research and Innovation agenda for NbS has stimulated many research projects, for an estimated volume of around EUR 200 million, including CONNECTING Nature, GROW GREEN, JUSTNature, NATURVATION, Nature4Cities, SOILGUARD, ThinkNature, We Value Nature and NetworkNature. These projects have produced an enormous body of knowledge and evidence across a wide spectrum of NbS.

recreation. The combined benefits of mangrove preservation and restoration are estimated to be up to 10 times the costs (Heubaum et al., 2022[59]). Besides reducing the impact of natural hazards such as flooding, landslides or storm surges on communities, wetlands also offer other significant ecosystem services, including carbon sequestration, and biodiversity support, among others (Ponzio et al., 2019[60]).

However, in most cases, the growing understanding of the importance of NbS is not yet generally translated into robust, evidence-based policy targets. For example, only about 17% of NDCs with current or planned actions involving NbS for climate adaptation set quantifiable and robust targets. Likewise, although it is estimated that more 70% of NDCs contain references to NbS efforts in the forestry sector, only 20% have quantifiable targets (Seddon et al., 2019[61]). However, when 28% of the Paris Agreement signatory Parties updated their NDCs in May 2021, 80% of those that did refer to NbS for mitigation in their new objectives, with an increasing number of quantifiable targets (Bakhtary, Haupt and Elbrecht, 2021[62]). This suggests that there is considerable potential and willingness to strengthen the role of NbS in terms of design, implementation and quantification of benefits.

The UN Environment Programme, in its *State of Finance of Nature* report (UNEP, 2021[63]), found that NbS investment should be tripled to meet both biodiversity and climate change targets. The main challenge to increasing investment in NbS lies in quantifying the benefits of these solutions in order to prove their cost-effectiveness. Accounting for the value of nature in policy direction is complex because traditional methods of economic appraisal tend to fail to assess all co-benefits, leading to underinvestment in NbS (Seddon et al., 2020[64]). Furthermore, large-scale nature-based solutions face governance challenges as they involve a high degree of collaboration among different stakeholders, some of whom default to grey engineered interventions. This is one reason for the low NbS implementation rate by authorities in Europe (Finewood, 2016[65]; EEA, 2021[3]). In addition, the long time-frame required for the implementation of NbS tends to hinder the integration of such solutions into policy and planning (Wendling et al., 2018[66]).

Cost-benefit analysis, which measures the net gain or loss of an intervention, can encourage further investment in NbS when their economic profitability can be proven. However, consideration of solely on economic efficiency on its own can omit the wider social and environmental benefits of NbS. Assessing and quantifying these benefits is therefore crucial. Three main approaches are used to estimate the monetary value of ecosystem services that NbS provides (Croci, Lucchitta and Penati, 2021[67]):

- The first approach uses market price methods to look at people's willingness to pay. Ecosystem outputs (products), such as wood and fish, can be traded and their value estimated like any other market good. One market price method – the productivity method – calculates the contribution of ecosystem services, such as clean water, that serve as inputs to production to the benefits derived from the final good. Other market price measures – the hedonic pricing and travel cost methods – deal with ecosystem services that cannot be traded directly in the market, such as recreational experiences or aesthetic views. The price that people are willing to pay for related goods, such as the added value of a house with a sea view, is used to estimate their value.
- The second approach looks at imputed willingness to pay, i.e. what people are willing to pay to avoid the negative effects if the ecosystem service ceased to exist or was not available. This approach uses avoided damage, replacement cost and opportunity cost methods. In the case of floods, willingness to pay for the flood protection services of a wetland can be estimated by examining how much people are willing to pay to avoid flood damage in places comparable to those protected by the wetlands.
- The third approach uses surveys to estimate the expressed willingness to pay for ecosystem services that cannot be traded in the market or equated with other marketed goods. Using contingent valuation or choice methods, surveys are based on hypothetical scenarios or choices between alternatives to estimate how much people are willing to pay.

To date, assessments of the quantitative benefits of NbS for flood risk management are usually based on comparative evaluations of the effectiveness of NbS (Sahani et al., 2019[68]). They rely on statistical methods; geographic information systems and remote sensing; flood scenario analysis; and multicriteria analysis. Flood risk is defined here as a combination of hazard (climate and landscape), exposure and vulnerability (population and assets). With NbS, a lack of data complicates the development of models due to the need to be able to quantify and represent the hydraulic and hydrological functions of nature-based solutions.

Some countries have developed good practices to help public and private actors assess the economic value of NbS. In the United Kingdom, the Environment Agency has published guidance to develop NbS to reduce flood risk and find funds to implement their interventions. An assessment of natural flood management measures by the Scottish government found that the leading tool for appraising the benefits of NbS in flood risk management projects was a tool called B£ST – for Benefits Estimation Tool – that is used to evaluate and monetise the financial, social and environmental benefits of blue-green infrastructure (CIRA, 2019[69]; OECD, 2021[6]).

The concept of a triple dividend of resilience refers to the positive socio-economic outcomes and co-benefits generated by an intervention in addition to risk reduction (Surminski and Tanner, 2016[70]). In the context of flood management, the Zurich Flood Resilience Alliance (ZFRA) showed that every US dollar invested in risk reduction saves five dollars in future flood-related losses (ZFRA, 2014[71]). Although this analysis encompasses interventions beyond NbS, the careful integration of NbS into disaster risk reduction can only increase the multiple resilience dividend (Roezer et al., 2021[72]). Investing in healthy and well-managed ecosystems therefore presents a high-impact opportunity for both the public and private sectors.

Benefits of NbS can be seen, for example, in the Philippines, where a study showed that regrowing mangrove forests can significantly reduce economic losses from storms and floodings, which in turn reduces insurance premia (Earth security, 2022[73]). Another application is in the context of urban heat waves. Kats and Glassbrook (2018[74]) assessed the costs and benefits of city-wide adoption of cool roofs, reflective pavements, solar photovoltaic (PV) technology and increased tree and vegetative cover in Philadelphia and Washington, D.C. They found that such interventions would create large net benefits across dividends two and three, especially for low-income neighbourhoods, which are disproportionately negatively affected by adverse temperatures and poor air quality and are inherently less resilient to the impacts of a changing climate (Heubaum et al., 2022[59]).

To better account for these benefits, ZFRA developed the Flood Resilience Measurement for Communities (FRMC) framework, which includes the five capitals of sustainable livelihoods (5Cs), namely financial, physical, social, human and natural capital, as well as the four natures of resilience (4Rs), namely robustness, rapidity, resourcefulness and redundancy. Nature-based solutions are part of the FRMC framework's natural capital.

4 Examples of NbS adoption to address flood risk in OECD countries

The use of the NbS is widespread in OECD countries. Research and various projects showcase its benefits for tackling issues related to urbanisation and climate change adaptation, particularly in terms of managing water-related climate risks in Europe and the United States. For instance, the Netherlands' Water Act recommends the use of green drainage systems, while in London, green drainage systems such as rain gardens, permeable paving and infiltration trenches have been installed (OECD, 2020[4]). Sweden invested EUR 22 million in retrofitting drainage systems to incorporate natural measures, which led to a 50% reduction in run-off and an increase in biodiversity (European Commission, 2015[31]). The city of Portland, Oregon, has invested USD 8 million in anticipation of more frequent and intense precipitation due to climate change, allowing the city to save an estimated USD 250 million in stormwater management costs (Foster, Lowe and Winkelman, 2011[75]).

The Urban Nature Atlas, a database of nature-based solutions, includes 1 000 examples of NbS in the fight against climate change across the world. In this and the next section, we will examine instances where nature-based solutions have been used for flood risk management, first looking at selected cases from OECD countries and then moving on to examples from Dynamic Asia and the Pacific. This review includes insights from the Zurich Flood Resilience Alliance (ZFRA), which works with more than 100 communities in 13 mostly developing countries to improve their flood resilience. The role of natural capital is a key component in the resilience assessment framework that these communities are using. This has led to some of them piloting nature-based solutions. Examples from beyond ZFRA are also included to show the wide range of contexts and applications of NbS.

As these examples show, nature-based solutions can play an important role in reducing risks, climate adaptation, biodiversity protection, urban and rural sustainable agendas, health and sustainable livelihoods, and other policy areas. However, for many stakeholders the performance of nature-based solutions particularly under extreme hazard conditions and in the face of climate change remains unclear. The unequal coverage and analytical depth of existing performance assessments has contributed to relatively low investment in NbS by the public and private sectors. Nonetheless, the use of NbS is growing in OECD countries and governments are increasingly investing in these solutions (Table 2).

Table 2. Benefits and challenges identified in NbS case studies in OECD countries

City/region, country	Type, partners, source	Benefits	Challenges identified
Greater Manchester, UK	Urban greening; 12 partners from local government, universities, NGOs, and business, EU Urban Innovation Actions; (Natural England, 2021[76])	Cooling, drainage, public amenity such as value of enjoying leisure facilities	Scientific uncertainties, lack of policy and skills to deliver NbS on a national scale (UK Parliament, 2022[77])
Brague River, France	Floodwater retention, EU NAIAD project (Nature Insurance Value: Assessment	Flood risk reduction in the upper catchment; widening of the river corridor enhanced by	Designing solutions effective enough to reduce risks, as even a high level of ambition on retention measures has been found insufficient to prevent flooding; selecting

	and Demonstration); (EEA, 2021[3])	floodplain reconnection	and developing solutions based on physical evidence and accepted by “traditional” flood risk managers; considering other socio-environmental characteristics to make these solutions acceptable to stakeholders.
Hamburg, Germany	Green roofs; City of Hamburg; Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection; European Climate Initiative; (EEA, 2021[3])	Space-efficient leisure areas, improvements in the city's rainwater retention capacity; increased biodiversity; reduction of extreme temperature effects	Collecting enough evidence proving the effectiveness of green roofs for recognition within German standards for retaining and slowing down water runoff from buildings; proving to housing industry that the evidence does not show increased life-cycle costs; ensuring communication and dialogue to change practices and create demand for green roofs among residents and businesses.
Copenhagen, Denmark	Urban drainage; Municipality of Copenhagen; (Copenhagen Municipality, 2012[78])	Cloudburst management; expansion of the sewer network; around 300 surface projects focusing on water retention and drainage	Carrying out projects on private roads that may therefore need to be purchased; not impacting environmental conservation goals; ensuring co-operation between municipalities and among private landowners; finding solutions for treating stormwater to ensure proper water quality
United States: Oklahoma City, Oklahoma; Sebastian County, Arkansas; Mississippi River basin, Mississippi	Urban greening; Greening America’s Communities programme; (EESI, 2020[79]); (Gonzalez and Kuzma, 2020[80]))	Stormwater run-off reduction by incorporating pervious pavers, bioretention planters, riparian restoration, and bioswales to reduce stormwater runoff	Creating appropriate tools and policies to enable individuals to bear the risks of implementing NbS, usually done on a large scale, such as reconnecting landowners’ agricultural land to the floodplain
	Flood Hazard Mitigation Plan; Federal Emergency Management Agency (FEMA) Pre-Disaster Mitigation; (EESI, 2020[79]).	Reduction in flood-risk through tree planting around buildings and parking lots, green roofs	
	Flood Risk Management Plan; FEMA, US Army Corps of Engineers; (EESI, 2020[79]).	Floodplain reconnection; wetland restoration	
	Ducks Unlimited has launched reforestation projects along the Mississippi and Milwaukee Rivers (Marsh McLennan, 2023[81])	Reduce flood exposures, mitigate droughts, and promote urban recreation, generate carbon sequestration credits, develop innovative insurance solutions	
Along the Bay of Fundy, Nova Scotia, Canada	Saltmarsh restoration; Government of Canada, with the Disaster Mitigation and Adaptation Fund (DMAF); (Drever, C. et al., 2021[82])	Flood risk reduction through natural flood storage; improvement of dikes	
Puerto Rico	Coastal reef restoration; UC Santa Cruz, US Geological Survey (Storlazzi et al., 2021[83])	Flood protection for nature, people, and property	Benefits of restoration vary according to the location and characteristics of the reefs, with high benefits for restoration in shallow waters, close to shore and near areas with more people and property, and low benefits if restoration is done in deep waters and far offshore.
Japan	Eco-system-based disaster risk reduction (Eco-DRR) (Ministry of the Environment of Japan, 2016[84]) and (Ministry of the Environment of Japan, 2023[85])	Establish community’s resilience to natural disasters, conservation of biodiversity and ecosystem, and contribute to social and economic development of communities.	If Eco-DRR involves changes in the existing land-use patterns, it needs to be implemented over an extended time span to get understanding and consent from residents. The difficulty of quantitatively assessing the buffering function of ecosystems poses another challenge.

Source: Authors’ compilation.

For instance, in the **United Kingdom**, the government’s 25-year Environment Plan of 2018 made a commitment to take a “natural capital approach” to environmental protection. Legislation was passed in 2019 for a net-zero GHG emissions target by 2050, to be achieved with the help of nature-based solutions such as afforestation or peatlands restoration (House of Common Library, 2020). From 2017 to 2021, the government invested GBP 15 million (pounds sterling) for 60 natural flood-management pilot projects across the United Kingdom. Over those four years, the programme slowed and stored water upstream of 15 000 homes in areas at risk of flooding (UK Environment Agency, 2021[86]). In 2021 the UK Government (2023[87]) announced a new GBP 12.5 million pilot programme for "Nature-based Solutions for Climate Change at the Landscape Scale", that included funding of multiple flood risk management projects. In **Greater Manchester**, the Innovative Financing and Delivery of Natural Climate Solutions (IGNITION) programme aims to increase the city's infrastructure by 10% by 2038 through the creation of projects worth at least GBP 10 million that incentivise businesses and organisations to invest in nature-based climate change adaption solutions. However, a report published by the UK Parliament (2022[77]) indicates that the government's targets for NbS may not be met. The report calls for more research into the scientific uncertainties of NbS and argues that the UK government lacks the appropriate policies and skills to deliver nature-based solutions on such a large scale.

Germany is to receive EUR 16.4 billion in EU structural funding over the period 2021-27 (Nova Institut, 2021[88]), and at least 30% of the funds are to be used to protect the climate, while 7.5% are earmarked for the protection of biodiversity from 2024 and 10% from 2026. As a comparison, only about 1% of the funds in the 2014-20 funding period was specifically used in the area of biodiversity. Positive examples of the use of NbS in Germany include the promotion of green infrastructure in North Rhine-Westphalia, nature and landscape development in Thuringia, and peatland development in Lower Saxony. Overall, however, only a few projects across Germany relate to biodiversity and ecosystem services. The city of **Hamburg** has invested EUR 13.5 million over the past six years in promoting green roofs. The aim is to reduce flood risk by improving the city's rainwater retention capacity, while also increasing biodiversity, reducing extreme temperature effects and creating space-efficient leisure areas. Of a total of 100 hectares of green roofs to be developed in the Hamburg metropolitan area, 30 hectares had been created in 2021 (EEA, 2021[3]). The programme has been extended to 2024 and now foresees the development of green façades as well. To date, the city has devoted a lot of effort to raising awareness and communicating with different stakeholders, dedicating for instance a full-time communications officer, in order to overcome problems of confidence in the effectiveness of green roofs, fear of increased housing prices and negative effects such as increased insect hatch.

France adopted a Biodiversity Plan in 2018 with the objective of "deploying nature-based solutions for resilient territories". The government committed in 2021 to earmark 30% of France's climate funding for nature-based solutions by 2030 (Climate Transparency, 2022[89]). A successful example of NbS was carried out in the south of France, where flash flooding was occurring along the **Brague River**, which flows through Antibes. The widening of the river corridor enhanced by floodplain reconnection enabled a reduction of 50% in run-off hazard and was able to reduce damage by 40-45%. These nature-based solutions were found to have lower implementation costs than grey solutions for the same level of risk reduction, reinforcing the evidence of their cost effectiveness (EEA, 2021[3]).

In **Denmark**, following cloudbursts in 2010 and 2011 that caused damage evaluated at EUR 1 billion, the city of **Copenhagen** issued a new climate adaptation policy integrating NbS into flood management plans (Copenhagen Municipality, 2012[78]). A socio-economic cost-benefit analysis found that continuing to focus on traditional sewage systems would result in a negative societal gain: despite capital investments, financial damage from flooding would remain high and not justify the high investment in implementation of traditional measures. The analysis found that combined blue-green solutions would result in 50% greater total savings than the conventional approach. The combined solutions consist in expanding the sewer network and around 300 surface projects focusing on water retention and drainage that have begun to be implemented in recent years.

Flooding poses a major risk in urban areas in the **United States**, and programmes funded by federal agencies such as the Federal Emergency Management Agency (FEMA) are looking at NbS to reduce flood risk (EESI, 2020[79]). For instance, the Greening America's Communities programme supports green infrastructure and sustainable design projects in cities and towns across the United States. The

Environmental Protection Agency provides design and technical assistance to help implement these projects. In 2016, Greening America's Communities helped **Oklahoma City** to address flooding and city connectivity issues. The programme redesigned five parts of the city to incorporate pervious pavers (porous paving), bioretention planters, riparian restoration and bioswales (shallow depressions) to reduce stormwater runoff. FEMA's Pre-Disaster Mitigation (PDM) grant programme provides resources to reduce or eliminate the risk of repetitive flood damage. In the **Mississippi River basin**, flood-related damage could cost up to USD 4.2 billion per year by 2030, an increase of USD 831 million from 2010 (Gonzalez and Kuzma, 2020[80]). Traditional levees have been widely used for flood protection, yet despite providing an illusion of protection they have led to an increase in the level and speed of the Mississippi, which in turn has created a heightened risk of flooding. Meanwhile, the expansion of agricultural activity into flood-prone areas led to the loss of 85-90% of the Upper Mississippi River's native wetlands, which served as natural flood storage (Dahl, 1990[90]). To reduce the risk of flooding, nature-based solutions have been implemented and setback levees have been created. At the individual level, hybrid flood mitigation solutions are being promoted by federal agencies such as the US Army Corps of Engineers and FEMA for landowners to reconnect some of their agricultural land to the floodplain (Gonzalez and Kuzma, 2020[80]). One study found that 8 000 hectares of reconnected floodplain would protect approximately 26 000 hectares of farmland from flooding (Opperman et al., 2009[91]). Because these solutions work on a large scale and the risk is difficult for individuals to bear, appropriate policies and funding are needed to ensure large-scale implementation and adequate compensation (Gonzalez and Kuzma, 2020[80]).

In **Canada,** researchers found that natural climate solutions could help reduce more than 10% of the country's total emissions (Drever, C. et al., 2021[82]). Canada's USD 1.6 billion Disaster Mitigation and Adaptation Fund (DMAF) enables better management by communities of risks from natural hazards like floods, wildfires and droughts through investment in natural and constructed infrastructure. For instance, a USD 20 million investment is restoring saltmarshes and improving dikes along the **Bay of Fundy** in Nova Scotia. The project will reduce coastal flooding for tens of thousands of residents and businesses, world heritage sites, indigenous communities and more than 20 000 hectares of farmland.

In **Puerto Rico**, a study was conducted to assess the social and economic benefits of potential coral reef restoration along the entire coastline (Storlazzi et al., 2021[83]). Coral reefs have been shown to reduce the risk of flooding significantly by breaking waves and dissipating their energy (OECD, 2021[6]). The assessment was conducted after Puerto Rico's coral reefs were damaged by hurricanes in 2017. The results showed that restoring the reefs could prevent more than USD 42 million in flood-related damage each year, while the benefits of reducing direct flood damage to public and private property were estimated at an additional USD 28 million. The benefits of natural defences are generally not assessed in the same economic terms as engineered defences; this study was the first rigorous quantification of the flood protection provided by coral reefs at a regional scale.

In **Japan**, the government is promoting the use of Ecosystem-based Disaster Risk Reduction (Eco-DRR), an approach that aims at reducing disaster risks by utilising the disaster mitigation functions of healthy ecosystems (Ministry of the Environment of Japan, 2016[84]). Eco-DRR is expected to bring various benefits to the environment (e.g. increased biodiversity and ecosystem conservation, absorption and accumulation of carbon dioxide, heat wave risk mitigation), society (venues for environmental education, community building through local activities, formation of a pleasant landscape), and economy (increased value of real estate, and tourism resources) (Ministry of the Environment of Japan, 2023[85]). One example of an Eco-DRR initiative is the Protection Forests identified by the Forestry Agency for disaster prevention purposes. Logging and land-use conversion are restricted at these sites and erosion control projects have been implemented. These areas help prevent landslides, and damage from wind or snow, thereby protecting soil and conserving headwaters. Outside of disaster periods, Protection Forests areas conserve biodiversity, offer health and recreational services, and produce consumable materials such as timber and food (Ministry of the Environment of Japan, 2016[84]).

5 Challenges to NbS adoption in Dynamic Asia and the Pacific: Case studies

Most research on NbS has been conducted in OECD countries where population growth is relatively low and urban planning is regulated, while literature is limited on NbS implementation, particularly in the Dynamic Asia and the Pacific region. Indeed, various socio-ecological challenges in the region complicate the adoption of NbS.

One of the key challenges is that implementation of NbS may face challenges due to the concept being relatively novel. For instance, NbS may not receive the same level of political and financial support as grey infrastructure-based solutions. Another challenge for the region is the rapid increase in population growth and urbanisation. Rising pressure for housing and essential infrastructure is causing a loss of natural areas. The high density of the region's cities and informal settlements make it challenging to implement NbS or reap their benefits. For example, large-scale sustainable urban drainage systems (SUDS) are difficult to adopt due to limited public land and high land values in high-density urban areas. While micro or household-scale SUDS might appear to be an appropriate option, this would require strong individual or community participation, and implementation would face financial constraints due to heavy reliance on voluntary funding (Sagala et al., 2022[92]). In addition, NbS in urban settings may lead to gentrification and inequalities. For instance, housing near blue-green spaces is often expensive, leading to an uneven distribution of benefits with the elite benefiting the most (Van Voorst and Hellman, 2015[93]; Lechner et al., 2020[94]).

Urban areas in OECD countries have been retrofitted with NbS, but NbS may need to be integrated from the planning and design phases in the rapidly growing cities of Dynamic Asia and the Pacific. Long-term vision is needed, as rapid development, weak commitments and poor planning may lead to the loss of potential future areas for NbS (Lechner et al., 2020[94]).

In addition, design and delivery of NbS can be challenging given the environmental risks faced by the majority of countries in Dynamic Asia and the Pacific. Nature-based solutions generally encompass restoration of the environment. Another point is the potential for human-wildlife conflict. Biodiversity in Southeast Asia is rapidly declining due to the destruction and degradation of natural ecosystems associated with urbanisation, infrastructure development and exploitation of natural resources. For instance, Indonesia has the region's highest rate of deforestation and also the largest number of endangered animal species in the world (Renaud et al., 2021[95]). NbS have the potential to restore ecosystems and bring back wildlife. However, the high biodiversity of Southeast Asia, one of the world's most biologically rich regions, could create the potential for human-wildlife conflict once ecosystems are restored (Lechner et al., 2020[94]).

Despite these hurdles, many countries in Asia and the Pacific have implemented NbS to address flood risks in their national context. This chapter examines cases of NbS implementation for flood risk management in countries of Dynamic Asia and the Pacific and discusses the specific challenges each country faces.

The case of Indonesia

The Indonesian archipelago is highly exposed and vulnerable to disasters. Various types of flooding occur frequently in the country, with coastal and riverine ecosystems most impacted by floods. The severity of coastal and riverine floods is projected to increase due to climate change, resulting in greater exposure of the population to these hazards. For instance, the number of people affected by a severe river flood is expected to increase by 1.4 million by 2035-44 if no effective measures are taken for adaptation (World Bank and ADB, 2021[96]).

Moreover, Indonesia has the second-longest coastline in the world, with a significant part of its population living in low-lying coastal areas. This makes the country highly exposed to rising sea levels. An average sea-level rise of up to 50 cm is projected for 2040 compared to the baseline level in 2000 (Bappenas, 2020[97]). This threat puts settlements, infrastructure and facilities in jeopardy, ultimately compromising their ability to function optimally. In the absence of adaptation measures, the population at risk of permanent flooding in Indonesia could exceed 4.2 million people by 2070-2100 (World Bank and ADB, 2021[96]). The risk of coastal flooding is exacerbated not only by climate change but also by the high level of land subsidence, driven by excessive groundwater extraction.

Java, the largest island of Indonesia, is the area most impacted by floods, despite defences against flood events being among major priorities (Willner et al., 2018[98]). The flat, low-lying coastal plain in Northern Java is highly susceptible to subsidence and sea-level rise. Approximately 2.5 million people, or 20% of the population of Northern Java, reside in flood-prone areas. If these areas have 0.5 to 1 metre of subsidence, they are at risk of flooding from average storm surges (Willemsen, van der Lelij and van Wesenbeeck, 2019[99]). An analysis of flood hazards, conducted to assess the country's National Action Plan for Climate Change Adaptation, indicates that river flooding has the potential to increase in Java during the rainy season in the next decades (Bappenas, 2018[100]).

Indonesia's capital, Jakarta, a city of 10.5 million inhabitants, lies within the island of Java. Jakarta is located in a delta plain traversed by 13 natural rivers and more than 1 400 km of man-made waterways; approximately 40% of the city lies below sea level, in particular the northern areas close to the Java Sea (Van Voorst and Hellman, 2015[93]). The city is exposed to riverine flooding risk from water that flows from the southern hills as well as to coastal flooding risk. Efforts to address Jakarta's flooding problems have so far mainly been made through grey infrastructure and physical measures such as artificial canals, dams and sea walls. However, in the context of growing flood risk under climate change, the development of NbS will be important. A growing body of literature acknowledges the importance of NbS and its potential to address the country's flood problem (Kuller et al., 2022[101]; Pramono, 2021[102]; Wiyati, Marthanty and Soeryantono, 2020[103]). The current government's development agenda has several strategies involving nature-based solutions to address climate-related risks. For instance, the National Medium-Term Development Plan for 2020-24 places significant emphasis on managing flood risks through a programme called Restoring Four Critical Watersheds. The programme aims to reduce flood risk in critical watershed areas by greening 150 000 hectares of land and decreasing the impact of floods in four Indonesian provinces: Banten, DKI Jakarta, West Java and North Sumatra. Additionally, strategic actions within Indonesia's updated NDC (2022[104]) include the enhancement of ecosystem services in watershed management and the implementation of ecosystem-based adaptation (EbA) in coastal development. These actions also have the potential to contribute to reducing flood risk.

NbS for flood protection along coasts and rivers has been implemented by Indonesia's government, using Building with Nature (BwN) as a design approach. Building with Nature "aims to work with the forces of nature rather than opposing them" (Tonneijck, van der Goot and Pearce, 2022[105]). This approach was initiated through a public-private partnership under the leadership of the government and relevant NGOs. It was piloted in the city of Demak in Central Java, where previous efforts to protect the coastline from flooding and erosion using grey infrastructure had proved to be ineffective and costly (Tonneijck, van der Goot and Pearce, 2022[105]).

The Demak coastline is facing rapid erosion caused by many factors, including inadequate river management. Dams and embankments built upstream prevent the flow of mud and sediment to the coast, and there has been a significant loss of mangrove forests in the intertidal zone. These mangroves, which once slowed currents and waves, also held back mud in their roots, helping to protect and stabilise the coastline. Mangrove replacement with aquaculture ponds by farmers has turned the previously continuous mangrove belt into a few scattered patches, making the coastline more exposed and vulnerable to waves, storm surges, coastal flooding and tidal erosion. Efforts by local communities to replant mangroves to reduce flood risk and erosion have often not been effective, as the water became deeper and the waves stronger, washing away the newly planted seedlings.

In order to address these issues, semi-permeable structures made of local brushwood and bamboo were constructed and installed along more than 9 km of the Demak coast, with the participation of community members. The role of these structures is to mimic the roots of mangroves by slowing the currents and trapping sediment, allowing mangroves to grow in the newly trapped sediment behind the permeable structures. Over time, it is intended that the restored mangrove belt will gradually take over the role of the permeable structures and recreate a natural defence against further erosion (Tonneijck, van der Goot and Pearce, 2022[105]).

Additionally, abandoned and unproductive aquaculture ponds were donated by local communities and re-engineered to create favourable conditions for mangroves to grow. These structures have been successful in capturing mud, with the accumulation of approximately 25 cm of sediment in the first three years. This has helped to reduce coastal erosion and prevent marine invasion and land loss, despite challenges such as shipworms and storms that have damaged some structures (Tonneijck, van der Goot and Pearce, 2022[105]).

The strong involvement of local communities during the planning, construction and maintenance phases of the structures was a key factor in the project's success. This pilot project acted as a catalyst for positive changes among local communities and authorities. For instance, local beneficiaries actively promoted the BwN approach, leading the Demak Regency to allocate a budget for the maintenance of the structures by local communities. The communities took ownership of the structures in 2018, showcasing the good practices of effective community engagement and knowledge transfer.

The pilot project in Demak also led to the allocation of around EUR 2.5 million in funding from the national government for a marine spatial management programme. The programme aims to restore eroding coastlines with the use of more than 23 km of permeable structures at 13 sites within and outside Java. Scaling up NbS projects can be challenging, as each location and community has its own unique characteristics, requiring measures to be tailored specifically for them. Capacity-building efforts for NbS solutions are being carried out for government officials, the private sector and students.

One example of a problem that arose following installation of the semi-permeable structures was the disappearance in 2017 of new mangroves in an area west of Demak due to the excessive extraction of groundwater by industries, which enhanced land subsidence (Tonneijck, van der Goot and Pearce, 2022[105]). This poses a challenge for coastal restoration, as the sinking ground increases water levels. While the permeable structures have the potential to restore lost ground and move the coastline back to its original location, they can provide only temporary relief in the case of continued subsidence.

The challenges faced in Demak are representative of the challenges faced all along the coast of Java and Indonesia, where conserving and restoring mangroves is a crucial aspect of maintaining coastal integrity in the context of climate change (Willemsen, van der Lelij and van Wesenbeeck, 2019[99]). Regulations that address land subsidence are necessary due to its significant impact on cities, coastlines and deltas across Indonesia. Subsidence also poses a risk to the sustainability of NbS projects and hinders full landscape recovery along vulnerable coastlines. Considering that the land subsidence issue in Indonesia is strongly associated with excessive groundwater extraction, there is a need for strategies to provide alternative water supplies and regulate water use in order to protect underground water and prevent further land subsidence.

Another example can be taken from Pekalongan, a city in central Java, which has experienced extreme flooding and is at risk of permanent submergence (ZFRA, 2021[106]). As part of ZFRA, a results-based financing mechanism was developed to support the financing of nature-based flood resilience projects. The mechanism included community-based cash-for-work projects for mangrove planting, river swales for stormwater management or wetland rehabilitation. A main challenge identified in developing this financing mechanism was to be able to project and quantify the monetary benefits of the selected nature-based solutions.

The case of the Philippines

The Philippines is the country with the highest disaster risk worldwide. Many weather-related disasters in the Philippines are caused directly or indirectly by tropical cyclones or typhoons. These hazards often bring excessive rains, lead to frequent flooding. For instance, Typhoon Ketsana, locally known as Tropical Storm Ondoy, battered the Philippines in 2009 resulting in unprecedented damages. This event prompted the government to scale up its action on flood management. In 2012, the government launched a Flood Management Master Plan for Metro Manila that includes a set of priority structural and non-structural measures to achieve sustainable flood management.

In addition, the Philippine Development Plan 2011-16 acknowledged the inadequacy of existing flood management measures and aimed to develop efficient and adequate infrastructure for flood protection. This translated into an eightfold increase in the budget for flood protection over 2008-16 (Ishiwatari and Sasaki, 2020[107]). The results of this investment are not yet clear as there has been no noticeable decrease in the death toll and economic damage from floods. The subsequent Philippine Development Plan 2017-22 and the current Philippine Development Plan 2023-2028 also recognise the risks posed by climate change.

Flood risk in the Philippines has often been associated with the inadequacy of existing infrastructure. In Manila, for instance, many pumping stations are outdated and do not have enough capacity to handle even average levels of rainfall (Stoutjesdijk, 2018[108]). The city's rapid development has not been accompanied by the construction of new pumping stations to meet flood control needs in low-lying areas. Areas surrounding the city's waterways are often characterised by high population density, with dwellings encroaching over the water and disrupting water flow, and a significant share of informal settlers residing in inadequate housing near waterways, making them especially exposed to flooding. Furthermore, solid waste blocks waterways and access to pumping stations.

In an effort to address these challenges, the Metro Manila Flood Management Project was undertaken in 2017 with technical and financial assistance from the World Bank and the Asian Infrastructure Investment Bank. This was the first major action taken as part of the national government's 2012 Master Plan. The project has four components. The first, which aims to modernise drainage areas, involves the construction of about 20 new pumping stations and modernisation of around 36 existing ones, along with their associated infrastructure, including waterways and drainage channels. The second component involves minimising solid waste in waterways; the third focuses on participatory housing and resettlement; and the fourth consists of supporting the operation of the project management offices of the Department of Public Works and Highways and the Metropolitan Manila Development Authorities to ensure effective management and co-ordination of their respective parts of the project.

At a national scale, the government is currently preparing a Flood Risk Management Master Plan for six river basins in Luzon, Visayas and Mindanao. This falls under the Integrated Flood Risk Management project, supported by technical assistance from the Asian Development Bank (ADB). The project involves rehabilitating and constructing flood protection infrastructure in at least 51 locations, with the construction of spur dikes, improvement of existing drainage channels, rehabilitation and replacement of existing bridges, and widening of river channels.

The Integrated Flood Risk Management project also receives support from an ADB regional project that promotes the integration of NbS with grey infrastructure. Called Protecting and Investing in Natural Capital in Dynamic Asia and the Pacific, this project recognises the limitations of relying solely on grey infrastructure in the face of increasing climate-related hazards. The flood master plans can be integrated with NbS through an approach called natural river management (NRM). This approach is being used to assess flood and erosion problems upstream, midstream and downstream in the Abra, Buayan-Malungon and Tagum-Libuganon river basins.

The nature-based approach includes “room for the river” – the reviving of old river channels, the removal of obstacles and riverbank improvement with vegetation strips. For instance, downstream areas of the Buayan-Malungon river basin are highly exposed to river and coastal flooding, waterlogging and soil erosion. The presence of grey infrastructure, such as the old Buayan bridge downstream and the new Buayan bridge upstream, is believed to exacerbate flooding. The flooding affects approximately 39 000 individuals and causes annual estimated damage of USD 22.6 million (ADB, 2022[109]). The master plan for this basin proposes two strategies for the downstream areas, both of which involve the adoption of the “room for the river” approach. This involves removing dikes and bridges to create more room and permeabilising the new Buayan bridge to reduce obstacles. The strategies incorporate both grey infrastructure, such as the construction of dikes and jetties, and NbS, such as the construction of natural bypasses and restoration of mangrove forests.

The Tagum-Libuganon river basin, located in an area of Davao with high seismic activity, faces numerous challenges that amplify flooding in nearby areas. Regular flooding is commonly reported in the small communities of Tuganay, Alejal and Ising. The flood problem, with estimated annual damage of USD 3 million, is attributed to a combination of factors, including inadequate infrastructure and roads, narrow culverts and changes in river morphology driven by natural factors and human-induced activities, such as quarrying and dwellings in flood-prone areas. In addition, the river’s drainage channels are blocked by solid waste. The proposed interventions for the Tagum-Libuganon river basin take an integrated system approach, including the construction of bridges and culverts to accommodate peak runoff during major events, comprehensive land-use planning, and NbS including the restoration of the Ising wetland and the creation of a green river-like connection between the Tuganay and Ising rivers (ADB, 2022[109]).

Meanwhile, interventions in the Abra river basin, where flood and erosion regularly affect around 7 700 inhabitants and more than 5 500 hectares of agricultural land, are to be focused on giving room to the river to accommodate its natural meandering, braiding channel movement (ADB, 2022[109]). Along with the construction of grey infrastructure, such as dikes and revetments, the proposed interventions include implementation of building codes, resettlement of vulnerable communities and smart quarrying practices in which quarrying will be used to reduce riverbank erosion and flooding.

Feasibility studies of the different river basins in the Philippines confirm that there is no one-size-fits-all solution. NbS is place-specific, and each river basin and coastal area has different natural characteristics and faces different flood risk and challenges. However, a lack of guidelines, rules and evidence hampers NbS implementation. Challenges to adopting NbS can also come from institutional and legislative barriers.

The case of the Mekong countries

The ASEAN countries through which the Mekong River flows are Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam. Seasonal flooding in the Mekong region plays a key role in maintaining agricultural production in delta areas. Local communities have leveraged their traditional knowledge and experience to make the most of this periodic inundation. Nevertheless, the increasingly unpredictable nature of floods is becoming a major issue, with increased frequency of flash flooding and severe riverine and coastal flooding (Furmage, 2022[110]). In recent years, floodwaters have become deeper and longer-lasting and damage and losses are increasing, especially in rapidly expanding peri-urban areas that lack adequate drainage systems. In Viet Nam, for instance, the estimated economic losses from flooding amount to approximately 1.5% of GDP annually. These costs are projected to rise to 3% of GDP by 2050 and could potentially reach as high as 7% by 2100 (World Bank, 2019[111]).

In Thailand, following a devastating flood in 1983, a Master Plan for flooding was drafted and significant investments were made to protect urban centres and exposed agricultural areas, with the construction of dikes and other flood control structures (Pavelic et al., 2012[112]). However, these structures were often designed without considering their wider environmental and social impacts, and without considering increasing flood risk under projected climate change in the area (ADB, 2016[17]). This leads to inadequately evaluated and planned projects across the urban landscape, which in some cases can increase flood risk (rather than reducing it) and require costly maintenance and retrofitting in the long run.

Consideration of the use of NbS for flood management in urban areas is becoming increasingly popular in the Mekong region. Several existing policies and strategies already support the implementation of NbS in the Mekong region's countries, as do their NDCs. For example, Cambodia's updated NDC in 2020 notes that ecosystem-based services are a means of improving resilience and the capacity to adapt to climate change. Lao PDR's NDC of 2021 prioritises NbS as a cost-effective approach to address climate-related disasters, including floods, landslides and droughts. Myanmar's NDC of 2021 includes a commitment to mitigate the impact of global climate change by promoting NbS as an adaptation measure. Thailand's NDC of 2021 includes ecosystem-based adaptation as a main principle to guide the formulation of the country's National Climate Adaptation Plan. Viet Nam's updated NDC recognises the role of NbS and EbA to minimise the damage associated with climate change in various sectors.

Most projects that incorporate NbS in the region are carried out with technical assistance from international development partners. One such project concerns the Cambodian town of Battambang, which is connected to the Tonle Sap Lake by the Sangker River. The town experiences frequent flooding during the rainy season (from June to December) due to poorly regulated developments. To address this, Battambang plans to rehabilitate a flood-prone canal along the town's western border by creating a green belt, and to transform the town's railway and wetlands area into a multi-use zone with natural drainage infrastructure (ADB, 2016[17]).

In Lao PDR, the town of Kaysone Phomvihane, the capital of Savannakhet Province, lies on the banks of the Mekong River. The city experiences annual floods and periodic tropical storms. A project supported by the ADB found that the town's southern floodgate and canal system provided inadequate flood protection. This issue was to be addressed by rehabilitating drainage canals using bioengineering techniques in order to reduce bank collapse and erosion, restore the natural stream drainage corridor and character, and provide more effective flood protection. A feasibility study suggests incorporating bioengineering techniques and rehabilitating the natural system of the northern floodgates as well (ADB, 2016[17]).

In Myanmar's capital, Yangon, the risk of flooding is expected to increase due to factors such as urbanisation, rising sea levels and land subsidence, particularly in the city's northeast areas, where subsidence is estimated to be occurring at up to 2 cm per year (Deltares, 2021[113]). Coastal wave surges, which occur during high tides and high river levels during the monsoon season, are among the primary causes of floods in the city and often result in deep inundation levels. The existing drainage system was found to be insufficient, leading to widespread flooding in low-lying areas during heavy rainfall events. Technical assistance for Yangon on developing an integrated flood resilience strategy is underway. The proposed strategy consists of two types of infrastructure investment: large-scale investments for projects such as building drainage canals, embankments, pumping stations and tidal barriers, which are more costly but may have a widespread impact on the entire city, and local-scale investments, which include sustainable urban drainage system measures, such as green roofs, infiltration systems and small retention ponds. The effectiveness of the sustainable urban drainage systems measures was evaluated in four pilot areas, and it was found that they can make a cost-effective contribution to both flood resilience and quality of life. However, these systems alone are not a complete solution to flood risk mitigation and on average can only contribute to up to 20% of overall flood resilience requirements (Deltares, 2021[113]). This implies a need for complementary traditional drainage infrastructure measures to achieve the flood risk objectives fully.

In Thailand, Bangkok has initiated several urban renewal projects aimed at improving the city's environment and reducing the risk of flooding by increasing the number of spaces such as urban forests, eco-friendly parks, green roofs and wetlands. One example is the Chulalongkorn Centenary Park, which opened in 2017 and was one of the first investments in urban NbS designed to reduce the city's flood risk. The park's design allows runoff to be slowed much more effectively than via regular concrete surfaces. Its on-site water management system allows the collection, treatment and storage of up to 1 million gallons of water, helping to alleviate the burden on the public sewerage system during heavy rains (UNEP, 2022[114]).

In Viet Nam, the town of Dong Ha, capital of Quang Tri Province, is facing increasing flood risk due to climate change. The town's vulnerability to flooding has been heightened by the destruction of natural systems through urbanisation. An existing box canal system and drainage basin has proved ineffective in controlling frequent small floods, resulting in worsened flooding in nearby residential and agricultural areas. Nature-based solutions proposed as part of an ADB project aim to address these issues by redesigning the entire 285-hectare basin into an attractive green zone with multiple functions, including a drainage corridor, water retention facility, landscape recreation area and water and air purifier (ADB, 2016[17]).

In addition, ecosystem-based adaptation measures have been planned and implemented in areas of Viet Nam suffering from riverine flooding and heavy rainfall, including Giang Lagoon, Bu Lu River Delta and Hue City (Bubeck et al., 2019[115]). In these areas, the population depends on water bodies for fishing and water supply (Van Tuyen, Armitage and Marschke, 2010[116]). The measures selected as appropriate disaster risk reduction (DDR) interventions had to support ecosystem services while protecting against flooding. Multiple dividends were considered, such as the reduction of damage and loss of life due to flooding, and the creation of new habitats for fisheries to improve livelihoods and tourism through mangrove planting. The restoration of a pond supported local small businesses through increased recreational value, and a flood resilience awareness campaign led to greater participation of women in local DRR decision making (Roezer et al., 2021[72]). However, due to the long time periods before ecosystems started to provide services, local decision makers were sceptical about the effectiveness of NbS for flood risk reduction. Meanwhile, a study revealed a mismatch between existing national government strategies on the connection of EbA with DRR and the knowledge of these local decision makers (Wolf et al., 2020[117]).

Despite growing recognition among government agencies in the Mekong countries that NbS can significantly contribute to addressing flood risk, challenges persist in incorporating NbS into mainstream practice. In general, current urban planning in the Mekong region does not facilitate the consideration of NbS and innovation, and in many cases, grey infrastructure investments have made the urban environment less resilient despite compliance with national and international development safeguards and procurement procedures (ADB, 2016[17]).

A green-building initiative in Bangkok presents an example of a good opportunity for greater inclusion of NbS in urban development. The initiative, known as the floor-area-ratio (FAR) bonus, provides developers with up to 20% more buildable space relative to the area of land on which the building is sited if certain features are included in the building design, such as low-income housing, green space, stormwater storage and participation in the Thai Green Build Institute certification programme (DFAT and AWP, 2022[118]). More NbS features could be included in the bonus requirements, such as raingardens and stormwater planter boxes.

The case of China

Severe flooding poses major risks to life, livelihoods and economic activity in China. Historically, Chinese water management relied solely on engineering measures, including dams and canals to manage water resources. More than 97 000 reservoirs have been built since the 1950s to improve the potable water supply, irrigation, hydroelectric power generation and flood control (Qi et al., 2020[119]). These dams are usually situated upstream of urban areas, allowing a reduction in the frequency of inundations in cities along streams and rivers downstream. However, urban expansion has amplified the damage caused by flash floods and fluvial floods, and pluvial and surface water flooding persists in Chinese cities due to significant reductions in green spaces (Qi et al., 2020[119]).

In October 2021, floods in Shanxi province displaced more than 1.7 million people. This added to the price tag of CNY 65 billion (Yuan renminbi) left by floods in Henan province just three months earlier. The growing damage and losses from floods have motivated attempts to increase local resilience and adaptative capacity, including through investments in flood detention areas and the restoration of wetlands. In 2016, the Kunshan Forest Park Company initiated an ecological renovation project aimed at enhancing the protection and restoration of the Kunshan forest urban wetland to improve water quality, drainage and storage capacity, and realise a range of other benefits. The company built several artificial lakes and wetlands, with water circulation systems continuously pumping lake water through the wetlands and then back to the lakes via small solar pumps to remove water pollutants. The lake system doubles as a rainwater storage space to improve overall capacity and control flooding. Wishart et al. (2021[120]) quantify first, second and third dividend benefits, including reduced losses from floods, higher real estate and commercial values, improvements in health, air quality and biodiversity, and carbon sequestration. The authors find that the project's overall benefit-cost ratio of 49.63 means that its benefits far outweigh its costs.

Another example is China's Natural Forest Conservation Programme (NFCP), one of the largest NbS programmes. The NFCP was implemented in 1998 following large-scale flooding attributed to deforestation. The programme aimed to protect China's forests mainly through a nationwide logging ban and a large-scale afforestation and reforestation policy that involved financial incentives for community monitoring of illegal logging. In China's Wolong National Nature Reserve, the contract essentially rewarded households for monitoring illegal logging in designated areas and sanctioned households (individually or collectively) for illegal logging (Martin et al., 2021[121]). Multiple co-benefits were identified by different stakeholders, namely flood and landslide protection, nature conservation and economic well-being via the development of nature-based tourism.

Although nature-based solutions may help to counter the growing risk of floods, their implementation may prove challenging. NbS require the involvement of numerous stakeholders, who must work together to design and carry out NbS projects. However, co-ordination between central and local governments, as well as neighbouring jurisdictions, poses a challenge (Moore, 2017[122]). It is crucial to address this issue, as effective nature-based solutions typically span across multiple jurisdictions. Establishing trustworthy relationships among governments, the private sector and public stakeholders to facilitate collaboration can also be a challenge (Qi et al., 2020[119]).

The case of South Asia

Urbanisation is on the rise in South Asia, characterised by complex urban infrastructure and an ever-increasing urban population. This exacerbates the effects of climate change and increases the risk of disasters. Floods are among the most frequent disasters in the region, affecting cities and wildland areas in Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka (Aslam, 2018[21]; Mukherjee et al., 2022[20]). Over time, the effects of floods have worsened. For instance, the Bangladeshi capital, Dhaka, had a well-functioning drainage and hydrological system in the 1950s due to the presence of 60 canals and a number of wetlands. However, with the city's rapid expansion and unplanned urbanisation, wetlands have declined by 30%, leading to difficulties in rainwater drainage, which in turn causes flooding during the monsoon season (Fernandes, Panwar and Sen, n.d.[123]).

Against this backdrop, NbS offer a promising strategy to tackle the growing risk of flood disasters in South Asia and enhance resilience. Several projects already implemented showcase practical examples of using NbS to address flood risk. One such example is the restoration of Hatirjheel basin in Bangladesh, which was approved in 2007 by the Executive Committee of the National Economic Council. Hatirjheel was transformed from a degraded, polluted and encroached area into one of Dhaka's largest stormwater retention bodies. The project aimed to enhance retention capacity by removing sludge and implementing slope protection measures, thereby safeguarding the surrounding area from flash floods. The project was completed in 2014 and now serves not only as an inspiration for restoration projects across Bangladesh, but also as a technical reference for waterfront development and urban design throughout the country (Fernandes, Panwar and Sen, n.d.[123]).

Another Bangladeshi example is a flood resilience project supported by ZFRA in 22 exposed communities on the floodplains of the Jamuna and Teesta Rivers (Bold, 2020[124]). The project, which is ongoing, is using ZFRA's Flood Resilience Measurement for Communities tool to develop a perspective on community resilience to flooding that results in sustainable interventions that can be measured and evaluated. Key lessons are emerging from the first phase of implementation, namely that natural capital is not currently prominent in flood risk management in Bangladesh, at least in the programme intervention areas, and that from both a policy and community perspective there is limited understanding of the role of natural capital in enabling communities to cope better with floods. In addition, early research highlights the critical need for a more balanced approach between grey, green and blue infrastructure, as the function of natural capital features, such as ponds, vegetation, channels, etc., changes according to the type of flooding. In other words, the role of natural capital in flood mitigation is likely to diminish when flooding is more severe than normal, suggesting that green and blue solutions may need to be supported by engineered solutions to adapt to changing flow conditions.

Another nature-based solution for flood risk management supported by ZFRA is the construction of bio-dikes by local communities in the Bardia and Kailali districts of Nepal (Khadka, 2018[125]; ZFRA, 2021[106]). These bio-dikes, which are significantly less expensive than grey engineering structures, have reduced flood damage to agricultural land, increased agricultural yields and enabled CO_2 sequestration and the creation of new wildlife habitats. In addition, after their establishment, they were found to mitigate landslides (Roezer et al., 2021[72]). Drawing on physical, natural, social and financial capital, the bio-dikes increased community resilience. However, the fact that bio-dikes require a longer time period than engineered dikes to reach full strength created a lack of support from local decision makers, while the unequal distribution of resilience dividends among the community led to conflict (Roezer et al., 2021[72]).

In Pakistan, the Earth Security organisation worked with CDC Group and Zephyr Power on a wind power project near Karachi, in the Indus River delta, the world's fifth largest delta system and seventh largest mangrove ecosystem (Earth Security, 2020[126]). The project recognised the importance of enhancing the site's ecological value and the role that mangroves could play in increasing climate resilience and bringing wider benefits to local communities. Earth Security estimated that the project could return 20 times its value in the protection of physical assets against coastal erosion, saving the project developer and its investors

USD 7 million over the project's 25-year time frame. The ecological value of mangroves has been integrated into the design, engineering and construction of civil infrastructure (road network, stream crossings, etc.). A proactive mangrove protection and rehabilitation programme and a community participation plan were central to the project, which is generating economic value for local communities in the form of job creation, local employment and a larger shrimp harvest.

However, the integration of NbS into policy remains inconsistent and fragmented in South Asia. For instance, a review of Bangladesh's national and sectoral development and climate change policies revealed that while EbA is acknowledged in most strategic-level policies, it is largely disregarded during policy formulation and implementation (Smith et al., 2021[127]). Challenges to upscaling NbS include the absence of implementation guidelines, inadequate financial support and insufficient mechanisms for monitoring and evaluating NbS initiatives. In Nepal, ecosystem-based adaptation is not prioritised or internalised in the government's development policies and plans. EbA is thus usually implemented at a limited scale with external aid and a predetermined time frame, making it difficult to secure the technical and financial support needed for long-term effectiveness and sustainability (Bhattarai et al., 2021[128]).

Raising awareness among governments and stakeholders about the benefits and success of NbS may help to scale up nature-based solutions in South Asia. In fact, practices, interventions and case studies are poorly documented, leading to a lack of dissemination (Bhattarai et al., 2021[128]; Tasnim et al., 2020[129]). Knowledge sharing can help address this issue. Several non-governmental organisations (NGOs) are leading initiatives to collect evidence and best practices from across countries and bring together a community of researchers, practitioners, entrepreneurs and policy makers. Examples of these initiatives include the NbS Bangladesh Portal and the India Forum for Nature-Based Solutions.

The case of the Pacific Island countries

The dual challenges of climate change and urbanisation in the Pacific Islands are placing increasing stress on the interconnected terrestrial and ocean ecosystems crucial for subsistence, livelihoods and well-being. In Kiribati, for instance, the impacts of climate change, particularly sea-level rise and shifting rainfall patterns, pose a significant threat to the population through coastal erosion, periodic flooding, soil salinisation and drought (Duvat, Magnan and Pouget, 2013[130]). In Fiji, the coastal town of Lami is susceptible to flash flooding during heavy rainfall and storm surges resulting from tropical cyclones (UNESCAP, 2019[131]). And in the Solomon Islands, the lower Mataniko River in Honiara faces riverbank erosion and flooding associated with poor waste management and sanitation practices as well as the growing population (SPREP, 2020[132]).

Pacific Island governments are placing increasing emphasis on NbS as a crucial component of climate-change policies and government priorities (Kiddle et al., 2021[133]), and various development partners are supporting these efforts. High-level policy documents prominently feature climate-change adaptation. For instance, Vanuatu's 2016-30 Climate Change and Disaster Risk Reduction Policy identifies targeted EbA measures that focus on soft intervention such as coastal revegetation, as opposed to grey infrastructure such as seawalls.

Palau has developed a national climate change policy that emphasises the importance of building ecosystem and community resilience. In Malekok State, located along the east coast of Palau's main island, the local community has developed a climate-smart guidance document in partnership with the Malekok State government and conservation NGOs. This document offers recommendations for updating existing infrastructure and designing future development in a way that reduces vulnerability to climate impacts. It puts special emphasis on ensuring that any new or refined infrastructure does not pose a threat to the marine ecosystem or water quality (Mcleod et al., 2019[134]). For instance, Palau's residential lease/housing programme incorporates sustainable designs and approaches to enhance ecosystem services and support resilience. The residential lease agreement requires revegetation of bare soil to reduce run-off into the coastal system and sedimentation, while also minimising stormwater flow.

In general, numerous projects in the Pacific Islands region can be categorised as NbS or EbA. Some are regional in scope while others are tailored to individual island nations or territories (Kiddle et al., 2021[133]). An example of a recent project is the Pacific Ecosystem-based Adaptation to Climate Change project, implemented in Vanuatu, Fiji and the Solomon Islands from 2015-20 by the Secretariat of the Pacific Regional Environment Programme (SPREP), with funding from the German government. The project includes hazard reduction in catchment areas through regulation and flood control and decreasing sedimentation in waterways.

The notion of collaborating with nature to develop sustainable human settlements that safeguard healthy ecosystems is not a novel one, despite the relatively recent proliferation of the term NbS. In fact, this idea serves as the basis for numerous indigenous belief systems and is relevant to many communities in the Pacific region despite their recent rapid urbanisation. However, there is still a lack of understanding, policies and actions, especially in the case of rapidly growing urban and suburban areas (Kiddle et al., 2021[133]). Lack of effective urban governance structures and mandates, along with fragmented local and national government structures, pose substantial barriers to the implementation of NbS in urban areas (UNESCAP, 2019[131]). This highlights the need for a more consistent and strategic approach to managing urbanisation. National urbanisation policies may promote the mainstreaming of urban NbS. Moreover, effective adaptation measures require thorough understanding of the local context and participatory approaches involving local communities. Therefore, NbS projects should recognise and explore traditional practices, especially those upheld by communities having a strong sense of indigeneity and a deep intergenerational connection to their lands. Integrating aspects of traditional nature-based knowledge and customary practices into NbS may provide more acceptable, appropriate and sustainable solutions for the Pacific region.

6 Strengthening finance and insurance for NbS

As shown above, nature-based solutions offer a range of benefits to communities and countries, but financial challenges often hamper the scaling up of existing NbS pilots. One particular area of concern is lack of finance. The OECD found that adaptation finance dropped by USD 4 billion in 2021, its share in global climate finance decreasing from 34% to 27% (OECD, 2023[135]). Limited access to appropriate finance remains a major barrier preventing the delivery of NbS to developing countries (OECD, 2020[136]). Closing this gap will require innovative approaches from both the private and public sectors. Insurance and financial services can play an important role in delivery of NbS.

Increasing awareness and understanding of NbS amongst investors and financiers is an important first step. The Taskforce on Nature-Related Financial Disclosure (TNFD) has been developing a framework since 2020 with the ultimate aim of "supporting a shift in financial flows away from nature-negative outcomes and toward nature-positive outcomes" (TNFD, n.d.[137]). The TNFD builds on and complements the Taskforce on Climate-related Financial Disclosure (TCFD), which has become a foundational global framework for mainstreaming the issue of climate-related financial risks. The TNFD aims to provide a framework for businesses to report on risks from ecosystem degradation and biodiversity loss. The data collected through the framework will in turn improve the availability of information and allow companies to integrate nature-related risks into decision making (KPMG, 2021[138]). The first beta version of the framework was released for market consultation in March 2022, released in late 2023. Increasing market awareness could lead to the TNFD becoming as important as the TCFD, as capital markets now expect climate data disclosure and regulators increasingly demand it. The TNFD demonstrates the increasing importance of nature in finance and policy planning and aligns with targets to reverse forest loss and land degradation by 2030. Those same objectives are targeted through the Finance for Biodiversity Pledge (FBP). In 2022, 98 financial institutions, representing 38% of global GDP, signed the FBP, endorsing 10 commitments aimed at protecting and restoring biodiversity through their investments and finance activities (Finance for Biodiversity, 2022[139]). This trend in disclosure and awareness could be reinforced by consumer demand for companies and investors to do more to protect the environment (Oliver Wyman Forum, 2022[140]).

Better data, remote sensing and new modelling tools are offering investors as well as insurers a better understanding of the role of nature in managing risks. This offers several opportunities including NbS, but also the reduction of nature loss, by recognizing the interdependencies between nature, climate and societal goals and ambitions (Marsh McLennan, 2023[81]). One example is Swiss Re's Biodiversity and Ecosystems Services index to assess and score the state of ten ecosystem services at 1 km^2 resolution (water security, timber provision, food provision, habitat intactness, pollination, soil fertility, water quality, regulation of air quality and local climate, erosion control and coastal protection). The index provides data on which countries and economic sectors are most vulnerable to biodiversity and ecosystem losses, and this facilitate underwriting and policy recommendations (Swiss Re, n.d.[141]).

Nature-based insurance and investment solutions can complement other economic and financial instruments, such as payment for ecosystem services, environmental taxes, tradable rights, and sustainable business model innovation.

Insurance instruments can reduce the financial impacts of climate disruptions, incentivise risk prevention, speed recovery and help to build up the resilience of communities, businesses and society in general. Insurers are also investors, risk advisors and knowledge brokers, with extensive expertise in the evaluation and management of risks. Under the term “nature-based insurance and investment solutions” (NBIS), efforts are made to identify the value of ecosystem services and translate this into financial instruments such as insurance, insurance-linked securities or green/resilience bonds.

An example of innovative financing of NbS for flood risk management was developed in Washington, DC, by the local water utility, DCWater (a public entity), using a performance-based or “pay-for-success” financing model. The company issued an Environmental Impact Bond, the first of its kind in the United States, with payment based on measured environmental results (World Bank, 2018[142]). The 30-year tax-exempt municipal bond between DCWater and private investors was issued in 2016, and the project’s goals were achieved in 2021, with green infrastructure providing a 20% reduction in stormwater runoff in the target area (Quantified Ventures, 2021[143]).

Another possible investment area for NbS comes in the context of infrastructure finance and city development: The worldwide built environment expanded by 66% in the first 12 years of this century, with most of the growth taking place in the Global South. Worldwide, 1.5 million people per week are expected to move to cities through 2030, and 70% of forests today lie within 1 km of man-made infrastructure (WEF, 2020[144]; WWF, 2021[145]). The impacts of this exponential urbanisation on nature and biodiversity are severe, and a “business as usual” approach to infrastructure development is not sustainable. WWF has found that infrastructure is one of the two main causes of habitat loss worldwide (WWF, 2021[145]). With cities and their infrastructure becoming increasingly vulnerable to floods, nature-based solutions present strong potential both to protect biodiversity and to reduce risks. Innovative planning, design and construction can enable a shift towards nature-positive built environment design. To classify as nature-positive for flood risk management, the infrastructure must be located so as to avoid, or at least minimise, the fragmentation or destruction of primary ecosystems, and must be designed in ways that are energy and resource efficient, promote biodiversity and ecosystem services, and build resilience to flooding. Finally, achieving sustainable, nature-positive infrastructure requires building on local knowledge, especially involving indigenous people in design and implementation (WEF, 2020[144]). Streetscapes, green roofs or raingardens are examples of such design for flood risk management.

There is a clear need to provide better access to capital markets, conditions and scalability of green instruments suitable for investment in NbS (IDB, 2022[146]). Private investors should be involved in infrastructure financing to accelerate its development while allowing for better long-term risk sharing in illiquid infrastructure investments (Adair et al., 2000[147]).

For insurers NbS offer several possible entry points: There are innovative insurance solutions emerging “that offer financial compensation or reimbursement for losses resulting from damage to a natural asset”, such as wetlands, forests or coastal reefs, on the basis of predetermined risk coverage limits (Melcer, 2021[148]).

There are opportunities to use insurance to protect biodiversity, enhance climate resilience, improve sustainable management of ecosystems and the economies and communities that depend on them, while increasing financial resilience. The existing insurance-related schemes or concepts that build upon ecosystem services and NbS offer some insights and lessons for the next generation of products and tools.

Most use cases of insurance for these purposes have been developed in the context of environmental, social and governance (ESG) strategies and are often pursued as a manifestation of corporate social responsibility in the insurance sector. There is clear potential for a substantial scaling up of insurance industry involvement in NbS, through insuring natural capital, incentivising NbS-related disaster risk reduction and divesting from nature-negative assets. Yet this can only be achieved following the resolution of key challenges, such as clearly demonstrating the financial materiality (i.e. significance) of ecosystem services for insurance and investments; the recognised insurability of risks that NbS set out to mitigate;

and the affordability of insurance premiums once the actuarial risks have been calculated and the beneficiaries identified.

Despite growing interest in nature-based solutions in the insurance sector, only a limited number of NbS projects measure adaptation and risk reduction benefits, and still fewer risk reduction or insurance projects quantify conservation benefits (Marchal et al., 2019[149]). One challenge faced by insurers is disclosure of the external costs of current investments in conventional infrastructure. A further issue is the need for better quantification and assessment of the long-term benefits of NbS approaches, which are difficult to quantify. The InsuResilience survey points to a lack of agreement on tools for assessing the benefits of NbS, with respondents relying on individual pilot studies rather than widely accepted methodologies.

Insurance and insurance-linked investments have demonstrable potential to contribute to filling the gap in finance for NbS, yet the role and benefits of NbS are currently not fully integrated into the design and implementation of insurance systems. Leading insurance initiatives such as ClimateWise, the Geneva Association, InsuResilience and the Ocean Risk and Resilience Action Alliance have made significant progress in aligning the sector with improved ESG performance and climate change ambitions. A new EU-funded initiative, Naturance,[4] is examining the technical, financial and operational feasibility and performance of solutions that combine disaster risk financing and investments with nature-based solutions. The aim is to stimulate dialogue, knowledge sharing and mutual learning across different areas of policy and practice. Naturance is tasked with producing a comprehensive and collaborative assessment of nature-based insurance and investment solutions from a societal and business perspective to encourage the adoption of jointly elaborated principles, performance metrics and recommended approaches for NbS. The InsuResilience Global Partnership has set up a Sectoral Community on NbS to learn from existing pilots about how to de-risk NbS through insurance and how to harness the value of natural capital for risk finance solutions by supporting assessment of the resilience impacts of NbS.

However, Toxopeus and Polzin (2021[150]) note that the lack of a generally accepted accounting and valuation framework for financiers could slow the growth of NbS on the basis of benefit assessment. Other scholars have raised concerns about socio-economic issues related to infrastructure investments in NbS, particularly in urban areas. Indeed, strategies for co-ordinating public and private funding for NbS often seek to identify a way to enable cost (and risk) sharing with actors who also obtain immediate benefits. Such NbS infrastructure investments would benefit affluent citizens and could therefore fail to provide widespread socio-economic benefits (Haase et al., 2017[151]; Kotsila et al., 2020[152]).

These issues, and the importance of NbS more broadly, are gaining traction in the policy arena. The United Nations Biodiversity Conference (COP-15), held in 2022, adopted the Kunming-Montreal Global Biodiversity Framework, which set key global targets for ambitious action by 2030. These include protecting at least 30% of the world's oceans and land, reducing pesticide use by at least 50% and eliminating plastic waste. The framework also mandates a substantial increase in finance for biodiversity, to at least USD 200 billion a year by 2030 (European Commission, 2022[153]). G7 countries have also signed the Nature Compact, committing them to protect and conserve at least 30% of the world's land area and at least 30% of the world's marine area by 2030, with the same percentage of national terrestrial, aquatic, coastal and marine areas also to be protected by 2030. The compact also commits them to including indigenous peoples and local communities in decision making and implementation, increasing investment in nature and directing a portion of public climate finance to nature (DEFRA, 2021[154]).

In 2021, a total of 220 NbS policies in 80 countries were identified and analysed by the NbS Policy Tracker (Nature4Climate, 2021[155]). While the report does not identify specific policies related to flood risk management, it shows that the most common NbS policies relate to coastal restoration (13.6%), which often includes flood risk management practices. The tracker also highlights that the vast majority of NbS policies (90%) recognise the importance of engaging diverse stakeholders, including businesses. The

[4] https://www.naturanceproject.eu/.

potential of NbS is increasingly recognised at international and national levels. More and more NbS projects are being developed for flood risk management, and there is a large and growing body of research on the topic. However, there is still a lack of NbS policies and regulations related to funding frameworks specific to flood-risk management, and this could hinder the expansion and mainstreaming of those practices.

7 Conclusion: An integrated and holistic approach to NbS implementation

The risk of floods is growing in many countries in Dynamic Asia and the Pacific. Finding ways to invest in ecosystem restoration and conservation can create significant benefits in terms of the reduction of flood risks. While implementation of NbS is becoming more commonplace, several policy reforms could help accelerate progress. Clear, common definitions of NbS and guidelines for tracking their financing would make these projects easier for policy makers and investors to understand. Developing standard assessment frameworks for NbS would allow policy makers to compare them to grey infrastructure-based solutions. For these solutions to reach their full potential, technical expertise in NbS and climate investing must be scaled up. Furthermore, insurance schemes that recognise the value of ecosystem services can create incentives for their protection, for example through premium discounts for properties protected from coastal flooding by mangrove forests.

Importantly, given the complex nature of risks and the interdependencies and expected changes, an appropriate combination of tools and a forward-looking approach is required. Relying solely on either NbS or grey infrastructure, on insurance or investments is unlikely to be sufficient to meet the heightened flood risk. A combined approach may offer better results in terms of flood protection, biodiversity and socio-economic benefits. A balanced integration of green and grey infrastructure in the Dynamic Asia and the Pacific region – adapted to the specific context, the type of flood risk faced by each area and the development of the market – could overcome the limitations of each individual approach and offer a more effective and sustainable solution. Adopting a proactive approach to managing water-related disasters is essential to implementing NbS effectively.

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