Helpdesk Report

K4D
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development

Nature-based solutions and water security.

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Question

What are some best practice examples of nature-based solutions for water security? What are some of the implementation challenges and lessons learned?

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1. Summary

Water security is important for sustaining livelihoods, human well-being and socio-economic development[1]. It involves safeguarding sustainable access to adequate quantities of acceptable water as well as protection against water risks. Achieving water security depends on a number of elements including natural processes, infrastructure, institutions and governance.

Water insecurity is increasing and nature-based solutions (NbS) can address some key water security challenges. Drivers of water insecurity include rising global water demands, population growth, rising agricultural demands to support food security, urbanisation, and climate change. Water availability is becoming more variable and unpredictable as climate change is altering the global water cycle, including increasing the frequency and severity of extreme events including floods and droughts. Water is essential for sustainable development, and in the context of climate change, upscaling NbS will be necessary to achieve the sustainable development goals (SDGs) (WWAP/UN-Water, 2018).

NbS protect, sustainably manage, and restore natural and modified ecosystems to address societal challenges (Cohen-Shacham et al., 2016). By improving the location, timing and quality of water, NbS can improve water supply and quality, contribute to disaster risk reduction and provide a number of co-benefits. NbS can support water security in both rural and urban settings and for a range of purposes including agricultural production and water, sanitation and hygiene (WASH). Situating NbS within wider discussions of water allocations between different users and jurisdictions can also help to mitigate trade-offs and tensions, and potentially increase cooperation as improvements to river health and environmental flows benefit all users. As such they can strengthen water security more broadly.

NbS is an umbrella term for a range of approaches and activities including source water protection, watershed management, wetlands restoration, protection, and construction, water harvesting, agricultural best management practices, afforestation, sustainable drainage systems and protecting mangroves, amongst others. Many of these approaches and activities, such as integrated water resources management, afforestation, and sustainable drainage systems, which are well-documented, are not new. However, the term NbS is relatively new, particularly with regards to being commonly used by practitioners and policy-makers.

Co-benefits that can be derived from NbS include improvements in human health, biodiversity, livelihoods and climate change mitigation and adaptation. For example, land conservation and water harvesting in Rajasthan, India has increased water security, increased productive farmland with gains for livelihoods, facilitated the return of wildlife and improved the position of women. In Peru, mainstreaming source water protection is addressing both climate and water security risks. To maximise co-benefits, they should be included in the design stage of an intervention.

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[1] UN-Water defines water security as "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (UNESCO, UN-Water, 2020).

NbS can also support strengthening water security for future pandemic preparedness and 'building back better' in light of Covid-19[2]. Water insecurity, including poor WASH services, can hamper measures to combat and suppress pandemics such as handwashing and social distancing. Linking NbS, social protection and public works programmes could support economic recovery following Covid-19[3]. For example, Pakistan's recovery efforts include the creation of over 63,000 jobs planting trees as part of a pre-existing programme to combat climate change[4]. In India, the UTFI (underground taming of floods for irrigation) project, which facilitates aquifer recharge, is registered with the Mahatma Gandhi Rural Employment Scheme allowing communities to be remunerated for participating (WWAP/UN-Water, 2018).

NbS are increasing in prominence on the policy agenda and in the investment decisions of a range of stakeholders. Reasons for this include: the need for water infrastructure investment is outpacing financial flows to the sector; climate change is challenging the resilience of grey infrastructure; and, the increasing need to find multi-purpose solutions that can address more than one problem. Investment in NbS by governments, water utilities and companies to support clean, reliable water supplies for cities and communities has increased from USD 8.2 billion in 2011 to USD 24.6 billion in 2015 (Bennett & Ruef, 2016; Bennett & Caroll, 2014). However, between 2013 and 2015, global private finance invested USD 3 billion in water infrastructure, predominately in grey infrastructure[5].

Grey infrastructure solutions for water security still dominate the policy agenda. The Asian Development Bank (2019b) argues that clear and constant dialogue is needed to build understanding, capacity and drive uptake of NbS by addressing government and private sector perceptions around expense, difficulty and time frames. Sharing pilot projects and data as 'proof of concept' can boost government confidence (ABD, 2019b). This could also help to overcome the skew in the evidence base towards developed country applications of NbS.

Examples of best practice

The breadth of NbS and the evidence base means that it is not possible to consider all types of NbS for water security adequately in one report, consequently, this report highlights the following:

- **Water for agriculture:** sustainable water for agriculture is vital due to rising food demands and the sector's dominance of water use (70% of all water withdrawals are for agriculture). NbS can improve water supply for rain-fed agricultural systems and support increases in crop production. Activities focus on soil and water conservation and include conservation agriculture, manuring/composting, vegetative strips/covers, agroforestry and water harvesting. Solutions such as sand dams can also, in some contexts, provide supplementary water for irrigation by facilitating groundwater infiltration. Managing diffuse

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[2] For more information see Cooper, R. (2020). *Water Security beyond Covid-19*. K4D Helpdesk Report 803. Brighton, UK: Institute of Development Studies.

[3] For more information see https://blogs.worldbank.org/endpovertyinsouthasia/green-economic-recovery-south-asia

[4] For more information see https://www.weforum.org/agenda/2020/04/green-stimulus-pakistan-trees-coronavirus-covid10-enviroment-climate-change

[5] https://www.edie.net/news/4/GWI---449bn-must-be-invested-in-water-annually-to-meet-SDGs/

run-off of excess nutrients from agriculture is the most prevalent water quality challenge globally. NbS can improve water quality by reducing nutrient and sediment run-off from agricultural land into water bodies through approached such as riparian grass and tree buffers, and vegetative waterways.

- **Source water protection and water funds:** healthy source watersheds collect, filter and store water and are important for urban water supply. Source water protection can reduce water treatment costs for cities, contribute to improved access to drinking water for rural communities, improve water quality for hydropower production and support resilience. Water funds are institutional platforms bringing together different water users to collectively invest in upstream habitat protection and land management, and mobilise innovative sources of funding (Abell et al., 2017). The Upper Tana-Nairobi Water Fund estimates that a USD 10 million investment in watershed conservation activities could lead to a return of USD 21.5 million including savings from wastewater treatment, increased power generation and increased agricultural yields.

- **Urban green infrastructure:** China's 'Sponge cities' utilise a number of green infrastructure approaches such as green roofs, pervious pavements, rain gardens and restoration of peri-urban wetlands to manage stormwater run-off, retaining some water for re-use. By 2030, the goal is for 80% of urban areas to use these methods to intercept, absorb and reuse 70% of rainwater. Other examples of urban green infrastructure include constructed wetlands for wastewater treatment and disaster risk reduction.

Combining green and grey infrastructure can improve storage and supply, lower costs, produce more resilient services, enhance system performance and better protect communities. The lifespan of Brazil's Itaipu Dam has been increased by implementing improved landscape management practices upstream of the dam funded through a payment for ecosystems services programme, resulting in improvements in the quality and quantity of water flowing into its reservoir. Combining the two recognises that grey infrastructure is embedded within watersheds and that its' functioning depends on healthy watersheds.

There is some evidence that green infrastructure performs equal or better than grey infrastructure and is cost effective in comparison. A blended approach including varying levels of both green and grey may be appropriate in a number of circumstances. Combining the two can also improve the climate resilience of grey infrastructure, which runs the risk of suffering from climate mismatch as climate change impacts unfold. Whilst there are knowledge gaps around how climate change will affect ecosystems (and therefore NbS interventions), they are more flexible than grey infrastructure and can support climate change adaptation.

Scaling up NbS

Scaling-up NbS faces a number of implementation challenges. Key findings from this rapid literature review include:

- **Finance:** currently only 1% of water resources finance goes to NbS despite their potential. This may partly be due to the barriers NbS present for financing, for example, there are challenges in valuing the benefits derived from NbS. Valuing ecosystem services is important for making a business case for investment in ecosystems as natural infrastructure and NbS. Communicating this value to policy-makers and decision-makers will be important to secure support. New funding instruments such as green bonds and water funds are appearing.

- **Scale and context:** effectiveness of NbS may vary by scale and context. Both geographic and temporal scale are important. For example, Water Funds operate over a number of scales, including individual farms and the watershed scale. Interventions should operate at the same scale as the ecosystems themselves to achieve impact. In some cases this may involve the need for transboundary cooperation. Temporal scale is important as the timescale over which benefits are realised may be longer for NbS than they are for grey infrastructure due to both hydrological processes, and the time needed to engage and coordinate stakeholders and build trust. Consequently, a monitoring and evaluation programme that fits the temporal scale of NbS is needed (Browder et al., 2019).

- **Equity:** there can be concerns about who benefits from NbS and how benefits accrue to different stakeholders. For example, changes in the timing or location of water could advantage some stakeholders and disadvantage others. Land tenure is also likely to be important as NbS can require large amounts of land. NbS may also have gender and livelihoods implications. Equity concerns have not been fully addressed in the relevant literature, but should be incorporated into programme design and understood by policy-makers.

- **Stakeholder engagement:** NbS often involve the need for cooperation across multiple stakeholders at scale, with local communities and rural land users responsible for undertaking land stewardship activities. Consequently, stakeholder buy-in and ownership is needed to achieve objectives. Partnerships and local communities' involvement in decision-making will be important for ensuring success. Strong political leadership is likely to be needed to coordinate the large number of stakeholders and institutions involved in NbS.

- **Technical guidance is also needed to support decision-making.** Current gaps include a lack of common criteria to assess both NbS and grey infrastructure against; a common matrix system for NBS including all relevant information such as type of risk, co-benefits, impact scale and the potential effects of climate change; and, a coherent set of parameters of standards for NbS. Browder et al. (2019) argue that currently, decision-makers often lack the information needed to adequately evaluate and compare green infrastructure options to business as usual.

There is a high degree of variation in how ecosystems impact on hydrology. For example, trees can increase or decrease groundwater recharge according to their type, density, location, size and age**.** Consequently, site-specific knowledge will be important in implementing NbS. The links between NbS and biodiversity are also complex and to avoid trade-offs biodiversity should be included in the design and impact assessments of proposed NbS interventions. The impacts of climate change on ecosystems and NbS are not widely considered in studies of NbS, but will be important considerations in the design phase.

The evidence base

The sources consulted for this rapid literature review suggest a number of knowledge gaps in the evidence base including: meta-analyses; robust and impartial assessments of current NbS experience; the hydrological performance of current NbS experiences; site specific knowledge of field deployment of NbS; timescales over which benefits are seen and experienced; and, cost-benefit analyses in comparison or conjunction with grey solutions (see for example, WWAP/UN-Water, 2018). The evidence base also appears to be skewed towards implementation in developed countries and South America, with some a small but growing evidence base related to China and Southeast Asia.

The rapid literature review largely draws on grey and academic literature, much of which is based on case study analysis.

2. Nature based solutions for water

Nature-based solutions (NbS) is an umbrella term referring to "actions to protect, sustainably manage, and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits" (Browder et al., 2019; Cohen-Shacham et al., 2016). Whilst the term was coined around 2002, some of the approaches grouped under NbS, such as source water protection and using natural infrastructure such as wetlands and mangroves for flood protection, predate the term. NbS for water can involve using or mimicking natural processes, conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems (WWAP/UN-Water, 2018).

Water-related ecosystem services directly influence the quantity and quality of water (WWAP/UN-Water, 2018). For example, forests, wetlands and grasslands, as well as soils and crops, play important roles in regulating water quality by reducing sediment loadings, capturing and retaining pollutants, and recycling nutrients (WWAP/ UN-Water, 2018). Soils are important for infiltration, run-off, and storage. Initial research by CIFOR on the Mau Forest Complex in Kenya between 2012 and 2016 found that forests supply clean water and also filter water from streams that come from agricultural land; forests recharge the water table as their soils facilitate the infiltration of rainwater, whereas agricultural lands have more overland flows that lead to erosion (Jacobs et al., 2016).

NbS for water can improve the location, timing and quality of available water, often simultaneously addressing water security challenges related to water availability, quality and water risks (WWAP/UN-Water, 2018). For example, approaches often address water supply by using or mimicking natural processes to manage water storage, infiltration and transmission (WWAP/UN-Water, 2018). Ecosystem forms of water storage include natural wetlands, peat bogs, improvements in soil moisture, and more efficient recharge of groundwater (WWAP/UN-Water, 2018). These forms of water storage can also influence water quality.

NbS are applicable in both rural and urban settings. For example, three types of solutions are applicable for addressing water availability in urban areas (WWAP/UN-Water, 2018):

- Watershed or catchment management to improve both supply and quality into urban areas.
- Improved recycling of water within urban water cycles e.g. wastewater reuse enabled through NbS to improve wastewater quality
- Green infrastructure: this includes measures such as reforestation, restoration or construction of wetlands, new connections between rivers and floodplains, water harvesting, permeable pavements and green spaces for bio-retention and infiltration.

Green infrastructure intentionally and strategically preserves, enhances, or restores elements of a natural system, such as forests, agricultural land, floodplains, and riparian areas (Browder et al., 2019). It is combined with grey infrastructure to produce more resilient and lower cost solutions (Browder et al., 2019). For example, NbS can improve water quality and therefore reduce water treatment costs.

Urban green infrastructure aims to manages hydrological pathways at the land/water interface and regulate run-off and groundwater recharge (WWAP/UN-Water, 2018). It has risen in prominence due to the application of 'sponge cities' in China. Managing water in cities is extremely important given the projected increases in the global urban population.

Nature based solutions can also help to reduce disaster risk (WWAP/UN-Water, 2018). In terms of **flooding and seas level rises**, there is evidence that intact coastal wetlands, including mangroves, can protect coastal communities from extreme weather events (and sea level rise) and their loss increases risk and vulnerability (WWAP/UN-Water, 2018). NbS including wetlands and flood plains restoration can recover ecological function and reduce flood risk (IUCN, 2016). Other NbS for flood risk management include (WWAP/UN-Water, 2018):

- Retaining water in the landscape through management of infiltration and overland flow e.g. land use changes, buffer strips and buffer zones, urban green infrastructure.
- Retain water in the landscape managing connectivity and conveyance e.g. river restoration, on-farm retention measures.
- Making space for water, e.g. wetlands, water storage areas.

Both natural and constructed wetlands can mitigate flood risk, acting as natural sponges trapping rain and surface run-off, mitigating land erosion and the impact of storm surges (often by diverting surface water into underlying aquifers) or protecting coastlines from storms (WWAP/UN-Water, 2018). Wetlands can also act as a reservoir during drought, and resource management practices can improve or modify these functions (Matthews et al., 2019). Wetland loss compromises the health and productive of ecosystems, alters the suitability of vast regions for food production and human habitation, and contributes to greenhouse gas emissions (UN Water, 2019).

A number of approaches address drought risks. For example, sunken sand dams and other water harvesting measures have been utilised in Kitui County, Kenya to increase water supply, benefitting health and livelihoods and reducing the potential for competition between users (GWPEA, 2016). Other examples include (Kapos et al., 2019):

- Agro-ecological practices can reduce crop vulnerability to drought. For example, during a severe drought in Brazil during 2008-9, losses in maize for farmers using these approaches were less than half of those using conventional practices.
- Traditional practices to protect and manage vegetation have enhanced tree cover tenfold in Niger's Maradi and Zinder regions, increasing soil fertility, crop yields, and drought resilience. This has led to surplus vegetables for export and reduced firewood collection times for women from 3 hours to 30 minutes.

NbS can also support river health and environmental flows, which contribute to human well-being and economic activity in a number of ways. This includes water supply, fisheries, and replenishment of sediment to low-lying delta supporting agricultural land (Tickner, 2017). River health depends on the interaction of a number of key elements including catchment processes, flow regime, habitat structure, water quality, and aquatic and riparian biodiversity: the flow regime (quantity, quality and timing of river flows) has been referred to as the ‘master variable’ (Tickner, 2017). Compromised river health, particular if environmental flows (the volumes of water needed to ensure critical ecosystem processes take place) are affected can have economic, social and geopolitical implications including impacts on food security and downstream communities (Tickner, 2017). Threats to river health include pollution, over-abstraction and poorly planned infrastructure (Tickner, 2017).

Situating NbS within wider discussions of water allocations will be important as improvements to the timing, location and quality of water could help to mitigate trade-offs between different uses and users, strengthening water security. In some contexts, maintaining or restoring critical aspects of river ecosystem health could be a catalyst for cooperation between different groups and help mitigate the socio-economic and geopolitical risks that can stem from declining river health (Tickner, 2017). As such, NbS could support cooperation and help to mitigate tensions between users including across jurisdictions. Enabling factors for interventions to support river health and environmental flows include: legislation and regulation; collaboration and stakeholder engagement; a driving force or champion; technical knowledge and tools; standards and guidelines; and, reallocation and trading mechanisms (Harwood et al., 2017).

Co-benefits

NbS can generate a range of co-benefits including social, economic and environmental. These include improvements in human health and livelihoods, ecosystem rehabilitation and maintenance, and the protection and enhancement of biodiversity. For example, land restoration and water harvesting activities in Rajasthan, India, following the worst drought in the state’s history in 1985-86 brought both water security and related benefits. These include: improved water security for 1000 villages; increased groundwater storage; productive farmland increased from 20% to 80% of the catchment, supporting livelihoods; the return of wildlife including antelope and leopard; and, gains related to the position of women (WWAP/UN-Water, 2018; Everard, 2015). Key enabling factors for success were the rebuilding of traditional village governance structures, and participation (communities designed and maintained water harvesting structures using indigenous knowledge) (Everard, 2015).

Other examples of co-benefits from NbS include:

- Preserving floodplains and/or reconnecting them to rivers to manage flood risk can also conserve ecosystem values and functions (Cohen-Shacham et al., 2016);
- Restoring or protecting coastal wetlands can increase resilience against storms with co-benefits including carbon sequestration, fish provision, job creation, or tourism (Martin et al., 2019).
- Constructed wetlands for wastewater treatment can produce biomass as a co-benefit (Avellan et al., 2018).

NbS can support climate change adaptation including increasing people’s resilience to shocks, increasing agricultural and aquaculture productivity and incomes, **as well as supporting climate change mitigation** (Kapos et al., 2019). Peru, with the support of USAID, is addressing both climate and water security risks through mainstreaming natural infrastructure through the Natural Infrastructure for Water Security Project, which focuses on source water protection

(SWP) amongst others (Matthews et al., 2019)[6]. This builds on experience supporting natural infrastructure through the Ecosystems Service Compensation Mechanism which allows utilities to use part of user fees for investments in watershed health (Matthews et al., 2019). Through this programme, landowners around source waters are compensated for good land stewardship (Matthews et al., 2019).

Poverty reduction co-benefits are potentially complex to quantify. NbS may improve fisheries, timber and non-timber forest resources, biodiversity, landscape values and cultural and recreational services, which in turn can lead to added socio-economic benefits that include improved livelihoods and poverty reduction as well as new opportunities for employment and the creation of decent jobs (WWAP, 2016).

In approaches that require farmers or local communities to adopt land and water stewardship practices, poverty reduction benefits can be varied. For example, there is some evidence from wetland restoration in Japan that farmers would need governmental support to implement practices that can both support biodiversity and conservation and provide sufficient income (Cohen-Shacham et al., 2016). There is also evidence more broadly from payment for ecosystem services programmes that there can be barriers to entry in the programme for the poorest.

3. Water for agriculture

Supply/availability

Sustainable water supply for agriculture is vital in the context of rising food demands due to population growth and urbanisation. Approximately 70% of globally water withdrawals are for agriculture. However, the main opportunities for increasing production are in rain-fed agricultural systems which account for bulk of current production and family farming ((WWAP/UN-Water, 2018). Consequently, co-benefits of applying NbS for agricultural water supply could include livelihood and poverty reduction benefits. Other co-benefits potentially include decreased pressures on land conversion, reduced pollution, erosion and water requirements, biodiversity savings; potential to reduce conflict between different sectors over water through improved system performance (WWAP/UN-Water, 2018).

Soil and water conservation measures for agriculture include conservation agriculture, manuring/composting, vegetative strips/covers, agroforestry, water harvesting, gully control and terracing (WWAP/UN-Water, 2018). An estimated 12.5% of cropland globally and 70% of cropland in South America is under conservation agriculture (CA). CA has three basic principles: minimum soil disturbance, permanent soil cover and crop rotation (WWAP/UN-Water, 2018). Agricultural systems that rehabilitate or conserve ecosystem services can be as productive as intensive, high-input systems, but with significantly reduced externalities (WWAP/UN-Water, 2018).

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[6] Source Water Protection aims to achieve human water security through sustainable ecosystem management including watershed management.

Estimates of the size of the water benefits from improving on-farm management practices that target green water[7] (rainfed crops) **are high.** For example, one study suggests potential gains could support a 20% increase in global crop production; whilst, a second suggests potential gains could be equivalent to crop production from 50% of current irrigation (WWAP/UN-Water, 2018). The theoretical gains that could be achievable at a global scale exceed the projected increases in global demand for water, thereby potentially reducing conflicts among competing uses (WWAP/UN-Water, 2018).

NbS could also improve the efficiency of irrigation. For example, catchment management to enhance groundwater and reservoir recharge (e.g. through reduced siltation that increases reservoir storage capacity), improved soil health through increased soil moisture retention and, better management of the soil ecosystem in irrigated fields could yield significant water savings (WWAP/UN-Water, 2018).

Sand dams as a water storage solution can provide supplementary water for irrigation and mitigate risks related to water availability (WWAP/UN-Water, 2018)[8]. Following an exceptionally dry rainy season in 2015-16 in Zimbabwe, the implementation of sands dams in the Sashane River meant that the riverbed still contained sufficient water for irrigation (WWAP/UN-Water, 2018). The use of sand dams in seasonal rivers to facilitate groundwater recharge can increase water supply in the dry season allowing farmers to extend the cropping season and harvest a second crop, in term providing opportunities to enhance incomes and livelihoods (WWAP/UN-Water, 2018).

Quality

Managing diffuse runoff of excess nutrients from agriculture, including into groundwater, is regarded as the most prevalent water quality-related challenge globally (WWAP/UN-Water, 2018). Climate change could lead to more extreme rainfall events, which could lead to higher contents of pollutants flowing into water bodies (WWAP/UN-Water, 2018).

NbS can rehabilitate ecosystem services that enable soils to improve nutrient management, and hence lower fertilizer demand and reduce nutrient runoff and/or infiltration to groundwater (WWAP/UN-Water, 2018). In addition to conservation agriculture and other measures outlined in the section above, the following can also improve water quality by reducing the nutrient and sediment run-off from agricultural land into water bodies (WWAP/UN-Water, 2018):

- **Riparian grass and tree buffers** along rivers and lake edges are a common and cost-effective approach. These vegetated areas have well-developed root systems, organic surface layers and understory vegetation that serve as physical and biological filters for runoff water and sediment that may be laden with nutrients and other agrochemicals.
- **Vegetative waterways** – drainage channels that remain under the vegetation cover where runoff conveyed from fields is filtered of sediment, nutrients and other agro-

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[7] Green water is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products (WWAP/UN-Water, 2018).

[8] At a simple level sand dams are walls across the river in the sand: by gradually increasing the thickness of the sediment layer in the river, the volume of water stored and its accessibility is increased (WWAP/UN-Water, 2018

chemicals through the physical contact with the vegetation and the filtering effect of the subsoil and underlying soil in the channel.

- **Water and sediment control basins** to divert runoff and to temporarily detain and release water through a piped outlet or through infiltration.
- **Wetlands**.

Some of these measures may 'take land' out of production, however this may not reduce overall production as studies have shown that agricultural systems that conserve ecosystem services perform as well as intensive, high-input systems (WWAP/UN-Water, 2018).

The water quality impacts of agricultural best management practices (BMPs), including some of the above measures, are well studied. Kroll & Oakland's (2019) synthesis of results from studies into how BMPs affect water quality and the ecological integrity of water bodies found a broad range of results. For example, different combinations of BMPs have resulted in 3-85% reductions in total nitrogen (Kroll & Oakland, 2019). The broad range of results suggests that effectiveness of NbS for water quality will depend on a number of factors, which should be considered when planning an intervention.

Factors affecting the effectiveness of interventions include (Kroll & Oakland, 2019; WWAP/UN-Water, 2018)**:**

- Local environmental factors such as geology, soil type and properties, precipitation regime, depth to groundwater, slope of the land, and farming practices including the crop types, the spatial and temporal extent of irrigation, rotation, and fertiliser use.
- Vegetation type, runoff velocity and infiltration rates, and maintenance (in the case of measures such as drainage channels, which can become clogged with sediment).
- Unexpected variation: for example, changes in the amount and timing of precipitation.
- Implementation variables: stakeholder buy-in, associated long-term maintenance and management, and regional influences, for example, land use changes upstream.

4. Water quality and availability

Source water protection

Healthy source watersheds collect, store and filter water and provide a number of benefits (Abell et al., 2017). These include biodiversity conservation, climate change adaptation and mitigation, food security, and human health (Abell et al., 2017). The world's largest cities often rely on water flowing from source watersheds hundreds or thousands of kilometres away (Abell et al., 2017). Degradation of source watersheds can have water security implications, for example, nutrients and sediment from agriculture (and other sources) can increase water treatment costs for cities; loss of natural vegetation and land degradation can change water flow patterns across the landscape and lead to unreliable water supplies (Abell et al., 2017). Considering the water security challenges faced by cities is important. By 2045, the world's urban population will increase to more than 9 billion (Matthews et al., 2019).

Source water protection can reduce water treatment costs for urban suppliers, contribute to improved access to safe drinking water in rural communities, improve water quality for hydropower production, support resilience and deliver co-benefits (WWAP/UN-Water, 2018; Matthews et al., 2019). For example, higher quality water flowing downstream translates into reduced water treatment costs and could have cost savings in terms of reducing the need for new treatment facilities. Source water protection activities include: targeted land protection (e.g. forests, grasslands or wetlands); revegetation; riparian restoration; agricultural best management practices (e.g. changing agricultural land management to achieve multiple positive environmental outcomes); ranching best management practices; fire risk management; wetland restoration and creation; and, road management (Abell et al., 2017; Matthews et al., 2019).

Abell et al. (2017) modelled the impacts of forest protection, pastureland reforestation and agricultural best management practices (using cover crops) for the source watersheds areas for 4,000 cities across the globe with populations over 100,000. Findings include (Abell et al., 2017):

- Four out of five cities (81%) can reduce sediment or nutrient pollution by a meaningful amount (at least 10%) through forest protection, pastureland reforestation and agricultural BMPs as cover crops.
- Globally, 32% of the world’s river basins experience seasonal, annual or dry-year water depletion. Source water protection activities could help improve infiltration and increase critical base flows in streams. For example, an analysis of the watersheds supplying water to six of Colombia’s largest cities shows that source water protection activities could increase potential base flow up to 11%. Activities like these will be especially important in the 26% of source watershed areas predicted to experience decreases in annual precipitation by mid-century.
- Source water protection can maintain or improve groundwater resources by targeting aquifer recharge zones or other sensitive areas of the landscape. For example, early results in San Antonio, Texas, suggest that land-based programs that have protected 21 percent of aquifer recharge areas may have already avoided pollution impacts.

Source water protection can be cost effective and potentially high impact globally. Abell et al. (2017) estimated that achieving an additional 10% reduction in sediment would cost USD 6.7 billion annually and could improve water security for 1.2 billion people at an average per capita cost of under USD 6 annually (Abell et al., 2017). 1-in-6 cities could pay for NBS solely through savings in water treatment costs (Matthews et al., 2019).

Source water protection can also potentially address climate change impacts and have a number of co-benefits (Matthews et al., 2019)**.** Rwanda has implemented SWP since 2002 after a mild drought sparked a short-term crisis by reducing hydropower generation in the Rugezi River (Matthews et al., 2019). Wetlands degradation due to a number of drivers, including population growth and agricultural extension, had interacted with the drought to reduce flows into the hydropower dams (Matthews et al., 2019). Rwanda implemented a number of measures to increase resilience including wetlands restoration, energy diversification and measures to ensure landless farmers had access to land (Matthews et al., 2019).

Abell et al. (2017) estimated a number of co-benefits from their modelling work:

- **Climate change mitigation:** If reforestation, forest protection and agricultural BMPs were fully implemented across all source watersheds, an additional 10 gigatonnes of CO2 in climate change mitigation potential could be achieved per year, or 16% of the 2050 emissions reduction goal.

- **Climate change adaptation:** regulate fire frequency, and better soil retention, strengthening resilience.
- **Human health and well-being:** reduced risk to fisheries as source water protection activities could help mitigate nutrient inputs for over 200 of the 762 globally reported coastal eutrophication and dead zones. Avoiding the loss of important pollinator habitat close to agricultural lands, source water protection could avert the loss of 5 percent of agricultural production's economic value globally from pollinator loss alone.
- **Biodiversity conservation:** reduced risk of regional extinction for over 5,400 terrestrial species. Increased habitat protection.

Water Funds

A water fund is an institutional platform bringing together different water users to collectively invest in upstream habitat protection and land management, and mobilise innovative sources of funding (Abell et al., 2017). They provide a framework for downstream users including cities, beverage companies, and utility providers to address water security issues at the source by investing in conservation projects that protect upstream lands, improving filtration and regulating flows (Matthews et al.,2019: 21). A water fund governance board selects projects, distributes funds, and monitors roject impacts (Abell et al., 2017). Pioneered in Quito, Ecuador, since the early 2000s, water funds have spread with 20 operating funds in Latin America, seven in the United States, one in Sub-Saharan Africa and one in China (Abell et al., 2017).

The Upper Tana-Nairobi Water Fund, launched in 2015, aims to secure Nairobi's water supplies while improving agricultural livelihoods[9]. The Fund brings together a range of stakeholders including water utilities, local government, and the forest service. It supports farmers in the watershed, through in-kind compensation mechanisms, to adopt water and soil conservation measures to improve water quality and supply downstream in Nairobi. The Fund predicts that a USD 10 million investment in its interventions could lead to a return of USD 21.5 million in economic benefits over a 30 year timeframe. This includes savings from water and wastewater treatment, increased power generation and increase yields for both smallholder farmers and larger producers.

Challenges to scaling up water funds as an approach include greater diversity and surety of cash flows (Abell et al., 2017). To date, public funding has been critical. Opportunities include: strengthening public funding flows, diversifying buyers by reaching out into new sectors, and positioning source water protection as a smart option for infrastructure investment beyond the values of savings in operations and maintenance costs (Abell et al., 2017). Other challenges for scaling up water funds include: gaps in policy and governance, adequate capacity to deliver, economies of scale in implementation, social acceptance, science and general awareness of source water protection's full potential (Abell et al., 2017).

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[9] For more information see https://www.nature.org/en-us/about-us/where-we-work/africa/stories-in-africa/nairobi-water-fund/

5. Urban green infrastructure

China's 'Sponge cities'

'Sponge cities' are a new strategy for integrated urban water management initiated in 2013 to mitigate severe urban water-related problems (Wang et al., 2018). Combining green and grey infrastructure, the 'Sponge cities' strategy aims to mitigate urban waterlogging (control flooding), control urban water pollution, utilise rainwater resources, improve water quality and restore ecological degradation of urban water (Wang et al., 2018). The overall aim to increase cities' resilience in the face of ongoing urbanisation, climate change and natural disasters (Wang et al., 2018). For example, combining stormwater engineering with flexible approaches to using green spaces can buffer water flows during extreme events (Smith et al., 2019).

Green infrastructure measures include: green roofs, vegetable swales, permeable pavements and bioremediation (Wang et al., 2018). These measures aim to utilise rainwater, recharge groundwater, reduce peak flows and purify rainwater (Wang et al., 2018). They are interdependent and function together to act as a 'sponge' (Wang et al., 2018). For example, rain gardens and bio-retention swales are used to collect run-off and remove certain pollutants, whilst restoring urban wetlands can help to absorb excess flows (WWAP/UN-Water, 2018). Some water is sent back to natural system and stored to ensure availability of water for irrigation and cleaning purposes during drought (WWAP/UN-Water, 2018).

Targets for the 'Sponge cities' strategy include: 70% of rainwater to be absorbed and re-used. This goal should be met by 20% of urban areas by the year 2020 and by 80% of urban areas by the year 2030 (WWAP/UN-Water, 2018). Initial results include alleviation of urban waterlogging, improvement of water-related ecosystems, promotion of industrial development and improved overall public satisfaction (WWAP/UN-Water, 2018).

River restoration

China is also investing in river restoration to strengthen water security, including in more than 40 cities (Speed et al., 2016a)**.** Water pollution and water scarcity issues are key challenges in China: in 2007 the World Bank estimated that water problems cost China the equivalent of 2.3% of GDP (Speed et al., 2016b). The government has devised 'three redlines' for water management: water use, water pollution discharge, and water use efficiency with targets at national, basin, provincial and local levels (Speed et al., 2016b). It is working to establish 'ecological redlines' to identify and protect the spatial limits of key ecosystems (Speed et al., 2016b). Objectives for river restoration, through the use of green and grey infrastructure, include improving water quality and availability, improved flood control, and improved amenity and related development opportunities (Speed et al., 2016a). Pilot projects are also being accompanied by government directives and standards for river restoration (Speed et al., 2016a).

Water sensitive urban design in Asian cities

Water sensitive urban design (WSUD) integrates water cycle management with the built environment through urban planning and design (ADB, 2019a). The Asian Development Bank (ADB) is piloting WSUD in four cities in Vietnam (Hue, Vinh Yen, Ha Giang and Ho Chi Minh City). WSUD combines a number of NBS including wetlands, vegetated swales, bioretention basins or artificial lakes, rain gardens, green roofs, permeable pavements, infiltration wells, and cleansing biotopes (ADB, 2019a). These can either complement or replace grey infrastructure depending on the specific purposes and localized contexts (ADB, 2019a).

WSUD could be most suitable for expanding cities in Southeast Asia that are exposed to climate change-induced disasters and environmental degradation, and bring a number of co-benefits (ADB, 2019). Potential co-benefits include: improved water quality, water conservation, mitigation of urban heat island effect, restored and enhanced urban ecosystems and biodiversity, and stimulating local economies by creating new jobs through stimulating new recreation and tourism services (ADB, 2019). For example, pond revitalisation in Hue, Vietnam has water quality, tourism, recreation and land value capture benefits (ADB, 2019b). In addition to WSUD, ADB is also supporting NbS to address flooding and subsistence, for example, in Manila Bay in the Philippines, and NbS projects in New Clark City (Philippines). Mandalay (Myanmar), and Visakhapatnam (India) amongst other cities (ABD, 2019b).

Lessons learned from piloting WSUD in Vietnam include: (ADB, 2019a):

- Strong and committed political leadership and good coordination among relevant agencies will be indispensable to make WSUD work.
- A citywide vision and goal should be set out: piecemeal implementation will lead to poor outcomes. NBS and WSUD should be integrated into urban planning guidelines and regulations. A comprehensive and integrated strategy/master plan should be developed to explore social, economic, climate, and environmental benefits.
- Community participation is a key factor for ensuring success: awareness on the advantages of rehabilitating and expanding water systems in cities should be communicated to the public and WSUD should be incentivised to stakeholders including the private sector and urban dwellers.

Constructed wetlands for wastewater

Constructed wetlands can be a low-cost, low-maintenance alternative to traditional wastewater treatment plants and have a number of co-benefits (Avellan et al., 2017). They have been implemented in multiple contexts including urban, peri-urban, rural, agricultural and mining in developed and developing countries. Studies estimate that constructed wetlands need less energy to treat wastewater compared to a traditional activated sludge plant, and can produce biomass without displacing other food or energy crops or placing burdens on water (Avellan et al., 2018). The latter could offset issues such as partly easing the reliance on unsustainable solid fuels in developing countries (Avellan et al., 2018). Other co-benefits include: additional ecosystem services, including aesthetics, biodiversity, wildlife refuge and nutrient capture for reuse (Avellan et al., 2018).

However, grey infrastructure solutions may still be needed as wetlands may have limited capacity to remove some industrial pollutants or loadings. Constructed wetlands have been successfully used for a range of industrial effluents including petrochemical, diary, meat processing, breweries, tanneries and others (WWAP/UN-Water, 2017). There is evidence that wetlands can remove between 20-60% of metals in water and trap 80-90% of sediment from run-off, however, less is known about their ability to remove some toxic substances associated with pesticides, industrial discharges and mining activities or some emerging pollutants (WWAP/UN-Water, 2018). Other challenges include:

- Wetlands may also have carrying capacities for contaminations and moving beyond these could lead to irreversible damage (WWAP/UN-Water, 2018).

- The physical space needed for constructed wetlands is larger than traditional technologies at an average of 7m2 per person (Avellan et al., 2017).
- There may also be a longer retention time needed to remove some pollutants compared to grey infrastructure. Related to this is the potential for accumulation of toxic substances in wetlands which could have ecosystem functioning and health impacts (WWAP/UN-Water, 2018).

Developed country findings

Urban green infrastructure are relatively well documented in cities in developed countries. A literature review of over 100 studies and a selection of case studies on NbS for urban water management in Europe found that NbS can mitigate flood and drought impacts whilst simultaneously supporting stormwater and water supply management (Oral et al., 2020). NBS are effective at purifying water from a variety of sources, which can reduce water production and treatment costs. For example, the closed-loop recycling of greywater can decrease the amount of potable water used and wastewater by up to 50–60% (Oral et al, 2020). The literature review also found that NBS have a number of co-benefits including increasing biodiversity, improving urban microclimates and socio-economic benefits such as enabling urban farming (Oral et al., 2020).

Studies suggest that green infrastructure performs equal or better than grey infrastructure and is cost effective when compared to grey infrastructure. Constructed wetlands and parks in Italy perform equal or better than grey infrastructure for water purification and flood protection, had similar costs, and provided co-benefits (wildlife support and recreation) (Liquate et al., 2016). In the USA, the city of Portland invested USD 8 million in green infrastructure and saved USD 250 million in hard infrastructure costs (Foster et al., 2011). Measures such as green alleys or tree planting have been estimated to be 3–6 times more effective in managing storm-water and reducing temperatures than conventional methods (Foster et al., 2011).

6. Combining green and grey infrastructure

Combining green and grey infrastructure can improve storage and supply, lower costs, produce more resilient services, enhance system performance and better protect communities (Browder et al., 2019). For example, the lifespan of reservoirs increases with the use of green infrastructure to control erosion (Browder et al., 2019). Brazil's 'Cultivando Agua Boa' programme which promotes improved landscape management and farming practices (through payments for ecosystems services to farmers) has increased the life expectancy of the Itaipu Dam by improving the quality and quantity of water feeding into it (Kassam et al., 2014). Sediment entering the dam's reservoir had reduced storage and increased maintenance costs, and therefore electricity generation costs (WWAP/UN-Water, 2018). The programme also delivers co-benefits including reduced nutrient run-off and farm productivity (WWAP/UN-Water, 2018).

Integrating green and grey infrastructure (such as dams, canals, and treatment plants) recognises that grey infrastructure is embedded within watersheds, and the hydrological and environmental attributes of these watersheds affect infrastructure performance (Browder et al., 2019). There is a general consensus within the literature that green infrastructure can complement grey by reducing the costs of engineered solutions, or could in some incidences replace the need for grey infrastructure (Kapos et al., 2019; Matthews et al., 2019; Abell et al., 2017). Often it may be the case that the choice is not between green or grey, but which blend of each is most appropriate and at what scale to harness synergies and improve overall system performance (WWAP/UN-Water, 2018).

Green infrastructure can complement grey infrastructure and diversify strategies for water security, which is important in the context of climate change (Vogl et al., 2017). In addition to being costly, grey infrastructure may lack climate resilience (Vogl et al.,2017). For example, there is a growing climate mismatch between the design parameters of large water infrastructure, such as Zambia's Kariba Dam and a non-static climate (Smith et al., 2019; Matthews et al., 2019). This affects performance and the Kariba Dam now only produces electricity for a few hours per day with economic consequences for both Zambia and Zimbabwe (Smith et al., 2019).

Challenges in integrating green and grey infrastructure include: a lack of technical guidance, tools and approaches to determine the right mix of NbS and grey infrastructure options and a lack of understanding on how to integrate them (WWAP/UN-Water, 2018). Vogl et al. (2017) argue that mainstreaming watershed services programmes as a cost-effective strategy alongside engineered approaches will require tools that lower institutional barriers to implementation and participation; structural market changes and standards of practice that account for the value of watersheds' natural capital; and, sharing success stories of replicable institutional and financial models applied in various contexts.

Example: groundwater recharge

Combining green and grey infrastructure can be effective at managing groundwater recharge. Techniques such as managed aquifer recharge, currently being implemented in the Windhoek aquifer, Namibia, intentionally enhance natural processes, for example, improving soil management to manage infiltration and rainwater capture (storing water in the soil for use in the dry season) supported by infrastructure (WWAP/UN-Water, 2018). In California, the Department for Water Resources is exploring flood-MAR using flood water from rainfall or snowmelt for groundwater recharge on agricultural lands, working landscapes, and natural managed landscapes. This combines green and grey infrastructure and extensive stakeholder engagement[10].

In India, IWMI (the International Water Management Institute) is supporting an approach called UTFI (underground taming of floods for irrigation). UTFI involves facilitating aquifer recharge to store wet season high flows in catchments, mitigating the impact of flooding, and tackling drought by making additional groundwater available for a range of needs including irrigation (WWAP/UN-Water, 2018). The UTFI programme is also registered with the Mahatma Gandhi Rural Employment Scheme allowing communities to be remunerated for participating (WWAP/UN-Water, 2018).

7. Implementation challenges

NbS are gaining visibility in policy and decision-making arenas, but scaling-up implementation includes a number of challenges. The ADB (2019b) argue that challenges for

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[10] For more information see https://water.ca.gov/Programs/All-Programs/Flood-MAR

implementing NbS include cross-sector collaboration, skills, data, land availability, longer timescales, and perceived investment risk. Addressing these challenges includes clear and constant dialogue to build understanding, capacity and drive uptake by addressing government and private sector perceptions around expense, difficulty and time frames; and, sharing pilot projects and data as ‘proof of concept’, which can boost government confidence (ABD, 2019b).

Finance

NBS can present barriers for financing and despite the increased focus on NbS only approximately 1% of the funding for water resources management supports NbS (Matthews et al., 2019; WWAP/UN-Water, 2018). The multilateral development banks are working towards consistently including NbS in their portfolios (Matthews et al., 2019). In terms of climate finance, NbS for water can pose challenges as they do not always qualify as ‘additional’: identifying the precise value of ‘additionality’ is challenging for water projects (Matthews et al., 2019).

However, new funding instruments are appearing. For example, in May 2019 the Government of the Netherlands issued a green bond, ‘one of the largest ever’ at EUR 5.98 billion (Anderson et al., 2019). This bond will finance, among other things, natural infrastructure solutions, including approaches such as Room for the River, which can protect the country from floods and sea level rise (Anderson et al., 2019)[11]. The Dutch Bond was certified by the Climate Bonds Initiative, who in 2018 issued Water Infrastructure Criteria (Anderson et al., 2019), which include criteria for both natural and hybrid water infrastructure projects[12]. The bond was oversubscribed by 3.5 times its amount within 90 minutes of issuance, suggesting there is market and demand for this type of green finance and investment (Anderson et al., 2019). There is an emerging sense that these types of finance could be utilised outside of developed countries. Water Funds, highlighted above are also an innovative funding approach.

Scale and context

The effectiveness and impacts of NbS may vary depending on the scale they are applied or assessed over. For example, Burek et al. (2012) modelled the effectiveness of 25 natural water retention measures on flooding in Europe. Findings include that these NbS could reduce a 1:20 year flood peak by up to 15% at the local level and 4% at the regional level, however, at some local levels NbS increased local flood peaks (Burek et al., 2012).

The spatial scale over which NbS are implemented is also likely to influence outcomes (see for example, Filoso et al., 2017). Kapos et al. (2019) argue that interventions should operate at the same scale as the ecosystems themselves to achieve impact. Ecosystems scales, e.g. river basin, flood plain etc., do not necessarily overlap with land ownership, administrative boundaries and political authority (Kapos et al., 2019).

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[11] The Dutch Room for the River programme involves restoring part of natural river floodplains. Flood prone areas are restored into wetlands, reservoirs or public parks that are designed to temporarily store flood water (Anderson et al., 2019).

[12] For more information see: https://www.wri.org/blog/2018/05/forests-and-wetlands-are-water-infrastructure-new-green-bond-helps-finance-their

An evaluation of river restoration[13] best practice by WWF and China's General Institute of Water Resources and Hydropower Planning and Design found that many restoration projects have failed as a result of working at the wrong spatial scale and failing to consider basin-level processes (Speed et al., 2016a). Operating at the river basin scale entails working with a broader range of stakeholders, and a larger number of planning and management instruments (Speed et al., 2016a). NbS projects should also consider the social and economic contexts in which ecosystems are set (WWAP/UN-Water, 2018). For example, restoration activities needs to understand what drove ecosystem loss in the first place in order to be successful (WWAP/UN-Water, 2018).

Quantifying benefits

Valuing ecosystem services is important in making a business case for investment in ecosystems as natural infrastructure and NbS (IUCN, 2016). A total economic valuation (TEV) of three of the five largest water towers in Kenya[14] estimated their value at USD 3.4 billion: almost 5% of Kenya's GDP (Ministry of Environment and Forestry, 2018). Within the TEV, regulating services (e.g. hydrological services, soil protection, carbon sequestration and gas regulation) contribute a much higher economic value than provisioning services (e.g. fuel wood for local communities).

Few frameworks exist for assessing the value of co-benefits of NBS and to guide cross-sectoral project and policy design and implementation (Raymond et al., 2017). A review of 1,700 documents found that NbS can have both co-benefits and/or costs across 10 societal challenges (including water) relevant to cities globally (Raymond et al., 2017). This suggests the need for both situating co-benefit assessment within policy and project implementation (Raymond et al., 2017) and context specific implementation.

Communicating the value of ecosystems to policy-makers is key. For example, CFIOR argue that communicating the value of Kenya's water towers can support sustainable management and conservation, particularly as they support the achievement of the government's development priorities[15]. Key activities include improving data collection, storage and sharing, promoting green infrastructure and increasing engagement with key industrial sectors, such as tea companies and hydropower companies to develop finance mechanisms that recognize the value of the water towers and their stewardships[16].

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[13] WWF and GWIP define river restoration as "ssisting the recovery of ecological structure and function in a degraded river ecosystem by replacing lost, damaged or compromised elements and re-establishing the processes necessary to support the natural ecosystem and to improve the ecosystem services it provides" (Speed et al., 2016a). This can involve both green and grey infrastructure interventions.

[14] Water towers are forested mountains in East Africa that contain many springs and streams that are the sources of major rivers. For example, the Mau Forest Complex in Kenya is the source of 12 rivers that feed into lakes Victoria, Natron and Turkana and support the livelihoods of 3 million rural and up to 2 million people in urban areas. For more information see: https://www.cifor.org/water-towers/

15 https://www2.cifor.org/corporate-news/findings-and-recommendations-from-the-kenya-water-towers-climate-change-resilience-program/

16 https://www2.cifor.org/corporate-news/findings-and-recommendations-from-the-kenya-water-towers-climate-change-resilience-program/

Equity

Quantifying the benefits of NbS and the trade-offs of implementing NbS is complex and there can be equity concerns about who benefits, how benefits accrue to different stakeholders and how benefits and costs are shared. For example, publicly funded watershed restoration projects can accrue benefits to both public and private stakeholders[17]. The Volkswagen Group in Mexico have supported NBS activities in conjunction with the National Commission for Protected Natural Areas to secure a reliable water supply, which has benefits for both the company and the city of Puebla (WWAP/UN-Water, 2018). Results include securing more than 1.3 million m³ per year of additional water for aquifer recharge, which is more water than the Volkswagen Group use annually (WWAP/UN-Water, 2018).

However, NbS do not create 'new water' as such, but influence the quality, timing or location of water. This may benefit some stakeholders and disadvantage others. The socioeconomic consequences of changes in water yields need to be considered (Filoso et al., 2017). There may also be uneven distribution of benefits and costs associated with implementing NbS (Bush & Doyon, 2019). For example, some farmers or households may lose land if agricultural or pasture land is reforested or paddy land is reclaimed for wetlands. Equity concerns have not been well-addressed in the literature related to NbS (Bush & Doyon, 2019).

Stakeholder engagement

NBS rely on local communities and actors to implement, manage and assess interventions. For example, in watershed restoration programmes, farmers are responsible for undertaking land stewardship for the benefits of downstream users: the costs for farmers are normally mitigated through transfers (Vogl et al., 2017). It is important to address potential equity concerns between upstream and downstream stakeholders. For example, in Water Funds, membership and access to decision-making processes can be selective with funds often managed by the stakeholders who pay into them (Hepworth et al., 2015).

Stakeholder engagement is also important for ensuring acceptance of activities. IUCN argue that to ensure acceptance at the local level both local communities and local government should be engaged in decision-making processes for designing and implementing NbS at scale[18]. They further argue that good governance of NbS requires creating local partnerships and identifying clear roles within these, including for women, and local governments need the capacity to implement, manage and monitor interventions on the ground – working with both communities at the local level and decision-makers at national level to align policy and practice[19]. In terms of urban green infrastructure projects participative planning can help to bridge the divide in terms of 'who pays' and 'who benefits' in relation to urban infrastructure (ADB, 2019b).

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[17] https://www.iucn.org/news/water/201903/behavioural-change-and-buy-who-do-we-really-need-impress-nature-based-solutions-water

[18] https://www.iucn.org/news/water/201903/behavioural-change-and-buy-who-do-we-really-need-impress-nature-based-solutions-water

[19] https://www.iucn.org/news/water/201903/behavioural-change-and-buy-who-do-we-really-need-impress-nature-based-solutions-water

Strong political leadership is needed to facilitate the need for cooperation across multiple stakeholders at scale (Kapos et al., 2019). Implementing NbS involves the coordinated action of many actors, for example, large numbers of small landowners in source watersheds (Vogl et al., 2017). There can be issues of trust, transparency, power dynamics and equity, as well little or no precedent for actors to recognise mutual interests or pre-existing incentives for cooperation (Vogl et al., 2017). Multi-scale co-management designs are particularly valuable when managing resources across boundaries e.g. transboundary waters (Cohen-Shacham et al., 2016).

8. Ecosystems: variation

Ecological processes in a landscape influence the quality of water and the way it moves through a system, as well as soil formation, erosion, and sediment transport and deposition – all of which can exert major influences on hydrology (WWAP/UN-Water, 2018). For example, ecosystems influence precipitation recycling from local to continental scales. Up to 40% of terrestrial rainfall originates from upwind plant transpiration and other land evaporation, with this source accounting for most of the rainfall in some regions (WWAP/UN-Water, 2018). Consequently land use changes in one place could have consequences for water and subsequently people and economies in other locations (WWAP/UN-Water, 2018).

Ecosystem degradation is widespread with implications for water resources. An estimated 64-71% of natural wetland has been lost globally since 1900, whilst the majority of the world's soils are in fair, poor or very poor conditions (WWAP/UN-Water, 2018). Soils are extremely important for the movement of water, with their condition influencing evaporation rates, infiltration, soil water storage, groundwater recharge, surface run-off and soil erosion (WWAP/UN-Water, 2018). NBS, as outlined above, involve at a basic level managing or enhancing some of these pathways.

Ecosystems' impacts on hydrology vary

There is a high degree of variation in how ecosystems impact hydrology. This includes both within and between ecosystem types or subtypes, their location and condition, their climate and management (WWAP/UN-Water, 2018):

- Trees can increase or decrease groundwater recharge according to their type, density, location, size and age.
- Tree-soil and moisture-groundwater relationships are also dependent on the size and age of trees in questions.
- Wetlands are widely reported to 'act like a sponge', thus reducing floods and preventing droughts, but some headwater wetlands can increase downstream flooding.
- Hydrological performance of soils varies widely between soil types, their condition, and their management.

Natural systems are dynamic and their roles and impacts change over time. Consequently, site-specific knowledge will be important for implementing NbS and generalised assumptions should be avoided (WWAP/UN-Water, 2018). For example, in terms of disaster risk reduction the effects of natural systems of water flows and storm surges depend on many factors including other land features, which vary across locations (WWAP/UN-Water, 2018). Their effects may also vary over time: evidence suggests that headwater wetlands in Southern Africa attenuate flood flows at the start of the rainy season, when they are relatively dry, but generate runoff and contribute to flood flow later in the rainy season, when they are saturated (WWAP/UN-Water, 2018). A major information gap is the lack of detailed quantitative understanding of the regulating functions of natural systems (WWAP/UN-Water, 2018).

Ecosystems also have 'tipping points' beyond which negative ecosystem change become irreversible. Attention should therefore be paid to the carrying capacity of ecosystems (WWAP/UN-Water, 2018).

At a general level, NbS support biodiversity, however in site specific incidences, NbS can involve trade-offs with biodiversity. Biodiversity underpins ecosystem processes and function, thus supporting the delivery of ecosystem services. Biodiversity loss can have negative impacts for water quality (WWAP/UN-Water, 2018). NbS often have positive biodiversity co-benefits, however, they can also, in certain circumstances lead to biodiversity losses. For example, in Europe, restoring underused farmland to riparian zones can lead to a loss in unique biodiversity in cases where farming was required to sustain it (WWAP/UN-Water, 2018). Consequently, biodiversity should be included in NbS impact assessment and if needed, there should be biodiversity safeguards in NbS implementation (WWAP/UN-Water, 2018).

Climate change, ecosystems and NbS

Climate change will impact ecosystem services, including through changing climate variability, increases in mean temperature, changes in precipitation patterns, sea level rises and extreme events (Kapos et al., 2019; Martin et al., 2019). It will alter the survival and distribution of species, contribute to ecosystem degradation and exacerbate the effects of unsustainable management (Kapos et al., 2019). Ecosystem changes related to climate change could challenge the capability of ecosystems to adapt and thus to deliver certain ecosystem services (Martin et al., 2019). This can reduce both water quality and availability (Kapos et al., 2019). Extreme events are also likely to increase in frequency and intensity and could overwhelm the ability of NBS to cope with these risks (Martin et al., 2019).

The impacts of climate change on NbS and ecosystems need to be considered in decision-making. NbS can have relatively high uncertainty levels due to knowledge gaps about ecosystems and species and their potential response to climate shifts (Matthews et al., 2019). Martin et al. (2019) argue that insufficient attention has been paid to climate change in studies of NbS. Any decision-making on a particular NbS requires scientifically based and customized information about the potential impacts of climate change (Martin et al., 2019). Climate change could affect NbS in two ways: one, their performance and effectiveness, and two, the costs that are related to dealing with and adapting to those impacts (Martin et al., 2019). For example, uncertainty about future hydrological conditions could mean that river restoration and flood control practices have to be re-evaluated in light of changing water flows (Cohen-Shacham et al., 2016). This could mean that a range of scenarios have to be considered during the design phase (Cohen-Shacham et al., 2016), particularly as interventions need to be resilient in the face of climate change.

9. Knowledge gaps

There is a lack of robust and impartial assessments of current NBS experience (WWAP/UN-Water, 2018). Evidence gaps include: the hydrological performance of current NbS experiences; site specific knowledge of field deployment of NbS; timescales over which benefits are seen and experienced; and, cost-benefit analyses in comparison or conjunction with grey solutions (WWAP/UN-Water, 2018). For example, there is a lack of well-established historic evidence of the positive impacts of NbS, which hinders comparing them with conventional water treatment technologies, which have a well-established evidence base of performance (WWAP/UN-Water, 2018).

The evidence base for different NbS is varied. A meta-analysis of the flow regulation capabilities of wetlands found that on average wetlands can reduce the frequency and magnitude of floods and increase the flood return period, augment low flows and decrease runoff and streamflow (Kadykalo & Findlay, 2016). However, there was a substantial variation in the estimated effects between studies (Kadykalo & Findlay, 2016). This suggests that context and scale will be important considerations for implementation.

The length of intervention is likely to be an important consideration. A meta-analysis of the impacts of forestry restoration and expansion projects on water yields found that in approximately 80% of studies water yields decreased (Filoso et al., 2017). However, most of the studies included in the meta-analysis were short-term, conducted in small catchments, focused on forestry and exotic species and increasing water yields was not an identified aim of the study (Filoso et al., 2017). Positive results were found for indirect measures of water yield including reductions in flood peaks and increases in soil infiltration (Filoso et al., 2017).

There is a need to increase knowledge to support decision-making (WWAP/UN-Water, 2018). For example, NbS are often assumed to be cost-effective: however, some solutions, particularly at scale, such as ecosystem restoration can require large investment (WWAP/UN-Water, 2018). More holistic cost-benefit analysis may be needed that can capture both hydrological and co-benefits (WWAP/UN-Water, 2018). There is limited knowledge of what NbS actually look like on the ground and their associated benefits over time (IUCN)[20]. The timescale over which NbS achieve their impact in comparison to grey infrastructure is a frequently raised concern (WWAP/UN-Water, 2018).

Common criteria are needed to assess both NbS and grey solutions as well as a classification for NbS which gathers together all information relevant for decision-making on NbS (WWAP/UN-Water, 2018; Martin et al, 2019). Common criteria should include all hydrological benefits, as well as the costs and benefits of ecosystem services (WWAP/UN-Water, 2018). In terms of a classification system for NbS to enable decision-making, Martin et al. (2019) argue that factors including type of risk, area, co-benefits, disservices, impact scale, and the potential effects of climate change on NbS have been insufficiently covered in current matrices.

There is also a need for coherent set of parameters or standards for NbS as a lack of operational clarity has presented a major obstacle to scale up (Cohen-Shacham et al., 2016). IUCN suggest a number of candidate parameters including: ecological complexity, long-term stability, scale of ecological organisation, direct societal benefits and adaptive governance (Cohen-Shacham et al., 2016).

The systemic implications of NbS should be considered to avoid intended benefits and services becoming disservices (Martin et al., 2019). For example, afforestation projects to

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[20] https://www.iucn.org/news/water/201903/behavioural-change-and-buy-who-do-we-really-need-impress-nature-based-solutions-water

control desertification may decrease water availability if non-suitable tree species are chosen (Martin et al., 2019). The Three Norths Shelter Forest Project, a large scale afforestation programme in China failed to take account of differences in typography, climate and hydrology, which increased environmental degradation with negative impacts on soil moisture, hydrology and vegetation coverage (Martin et al., 2019).

Identifying potential disservices is important for effectively evaluating the life cycle cost of NbS, including all the associated costs for designing, building and maintaining a functional NbS (Martin et al., 2019). For example, the vast majority of NbS require ongoing maintenance. A lack of funding or inefficient planning could cause management failures potentially resulting in decreasing ecosystems delivery, or loss of social acceptance (e.g. accidents due to urban green infrastructure not being properly maintained) (Martin et al., 2019).

10. References

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