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Nature-Based Solutions for agricultural water management and food security

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Contents

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Summary

Feeding the future world population sustainably and satisfactorily requires, among others, accessibility to water resources of adequate quantity and quality. Yet, conventional interventions solely based on ‘hard’ engineering solutions and infrastructural development have provided valuable lessons as they can compromise various ecosystem services that are required for stable water flows. Hence, calls for a shift in water management paradigms are justified and should prioritize in the political agendas. Nature-Based Solutions (NBS) offer a promising contribution on how to enhance the availability and quality of water for productive purposes and human consumption, while simultaneously striving to preserve the integrity and intrinsic value of the ecosystems. Implementing successful NBS for water management, however, is not an easy task since many ecosystems are already severely degraded, and exploited beyond their regenerative capacity. Furthermore, ecosystems are large and complex and the impact of interventions can only be assessed and analysed at a system-wide level. As a rule, many stakeholders are involved, as owners, users or caretakers, each with their own set of interests and values and it is not an easy task to reconcile these complex objectives and interests into a coherent set of principles and procedures. Simple market-based solutions such as partitioning of an ecosystem, attributing property rights and applying the polluter-pays-principle are often not sufficient for devising viable strategies.

Implementation of NBS requires a structured and comprehensive approach that starts with the valuation of the services provided by the ecosystem. The whole set of use and non-use values, in monetary terms, provides a factual basis to guide the implementation of NBS, which ideally is done according to transdisciplinary principles, i.e. complemented with scientific and case-specific knowledge of the eco-system in an adaptive decision-making process that involves the relevant stakeholders. To maximize intended sustainability and scale of NBS results, a system-wide, country-driven capacity enhancement approach needs to be applied that independently empowers people, strengthens organizations, institutions, multi-stakeholder processes as well as the enabling policy environment based on assessed needs.

In this discussion paper, twenty-one case studies of water management processes are analysed, using a non-representative literature survey, and checked to what extent they meet the requirements of the NBS implementation based on the criteria presented. It emerges that transdisciplinarity, stakeholder involvement, and well-designed funding schemes are important elements for successful implementation of NBS. Often, lengthy periods to organize participatory and transdisciplinary platforms are needed, which makes this process costly and as a result, complete implementation is often strained by funding shortages. Another common challenge in the surveyed examples is the minor role given to valuation of ecosystem services, an area for which the literature is still developing guidance while available valuation methods remain scattered, incomplete or imprecise. The less successful water management projects tend to suffer from inadequate factual and scientific basis and uncoordinated or insufficient stakeholder involvement. Successful case studies point to a satisfactory understanding of the functioning of ecosystems and the importance of multi-stakeholder platforms, well-identified funding schemes, and realistic monitoring and evaluation systems.

Context

Food and agricultural systems are under a set of pressures to, on the one hand, cater to an increasingly hungry population which demands not only more food, but also more resource-intense food, and on the other hand, tackle an intensifying competition over natural, human and financial resources, all subject to impacts of climate change. The natural resource base is already degraded to significant levels, and the business, as usual, is no longer an option.

FAO has been emphasizing the need to accelerate a global transition to sustainable food and agriculture systems, advocating an integrated approach to ensure sustainability in crop production, livestock, forestry, fisheries, and agriculture and in the management of natural resources (FAO, 2014a). This involves not only major increases in agricultural production but also major paradigm changes in the entire value chain. Increases in resource use efficiency and resource productivity are to be accompanied by improvements in storing, shipping, distributing, refrigeration, marketing, consuming, and recycling.

The green revolution that boosted crop production and agricultural yields was a result of the intensification of agriculture which entailed high-yielding varieties, irrigation and high levels of chemical inputs. The case for intensification has been well articulated in the literature, both from a perspective of increased production and from a conservation perspective, in terms of the millions of hectares of forests which otherwise would be converted into farm land, unquantifiable amount of ecosystem services saved, and of some 590 billion tons of CO2 prevented from being released into the atmosphere (Burney *et al*, 2010).

Most intensification in the past occurred with the primary aim of production, whose negative consequences are now well documented. We can mention soil and water pollution, soil acidification, salinization, and nutrient depletion. The lessons learned from the past tell us that the response is sustainable food and agriculture systems as the overarching principle, and sustainable intensification and diversification (SIA) in terms of production.

Achieving sustainability in food and agriculture has five pillars (FAO, 2014a):

i. Improve efficiency in the use of resources, especially water resources,
ii. Take direct and deliberate action to conserve, protect and enhance natural resources,
iii. Protect and improve rural livelihoods, equity and social well-being,
iv. Enhance the resilience of people, communities and ecosystems, and
v. Ensure responsible and effective governance mechanisms.

Through these pillars, the case is well made and acknowledged for a transformation to sustainable intensification and diversification in agriculture with an agro-ecological perspective. The Committee on World Food Security (CFS) has endorsed in its 42nd Session (CFS, 2015) a set of eight recommendations, first of which states “Promote an ecosystem approach and participatory mechanisms for the conservation, restoration and sustainable management of ecosystems, involving actors at the appropriate scales". Rockström *et al* (2017) describe the conditions and the elements of mainstreaming sustainable agricultural intensification (SIA) in order to reposition agriculture from being the major driver of global environmental change to a major contributor to the transition to sustainability through incorporating double objectives of increasing yields and enhancing the ecosystem services.

This means, in many areas, diversification of cropping and increases in yield will be mutually supportive with environmental improvements. In others, lesser yields or land reallocation to ensure sustainability will have to be counterbalanced by benefits such as biodiversity conservation, carbon storage, protection from floods and droughts, and recreation.

From a production perspective, SIA has 2 components, i.e. resource efficiency, which relates to combining locally relevant crop and animal genetic improvement and practices that minimize inputs and close nutrient, carbon, and water cycles; and landscape level resilience which relies on practices sustaining ecosystem functions and services.

Sustainable practices range across full domain of agriculture, including soil tillage systems, water resource management, crop and nutrient management, use of drought or heat resistant seeds, livestock practices, integrated landscape management, pest management, sustainable soil management, and managing the forest-water nexus. All of these have impacts on and are impacted by, the quantity, quality, and availability of water.

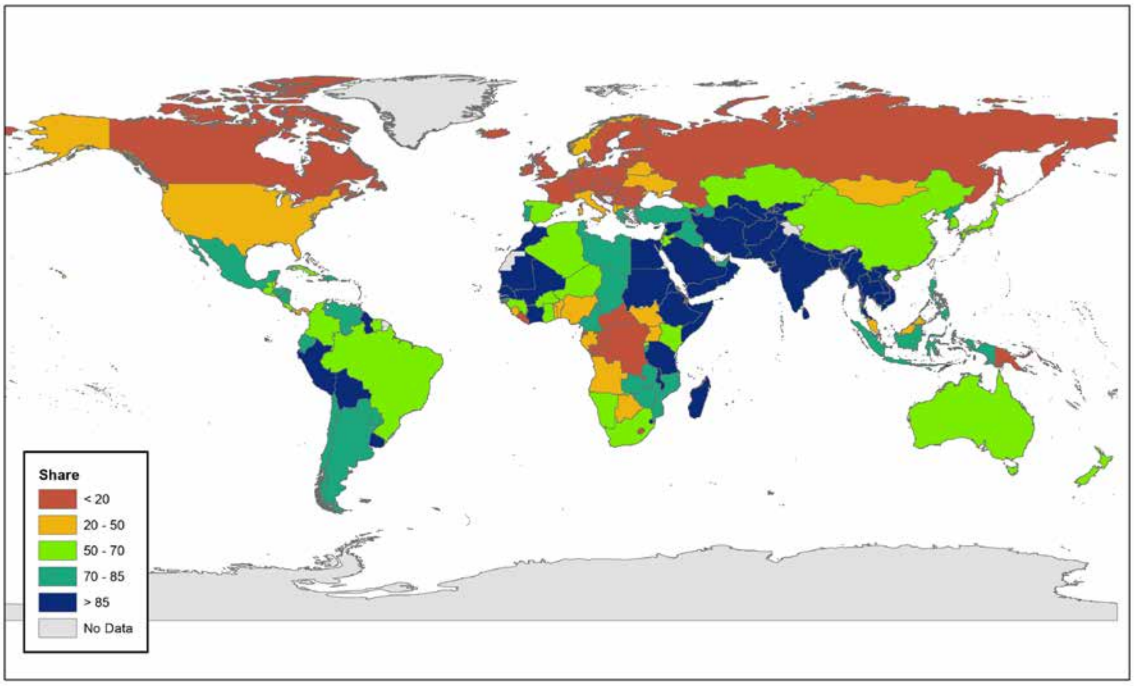
We have plenty of evidence, examples, and tools for the above to happen. The need is for upscaling the practices through deliberate and consistent policies.

Within this context, this discussion paper makes the case for the role that nature based solutions can play in making agriculture more productive while maintaining and preferably strengthening the integrity of the ecosystems from a lens of water resources management.

1. Increased demand for agricultural water

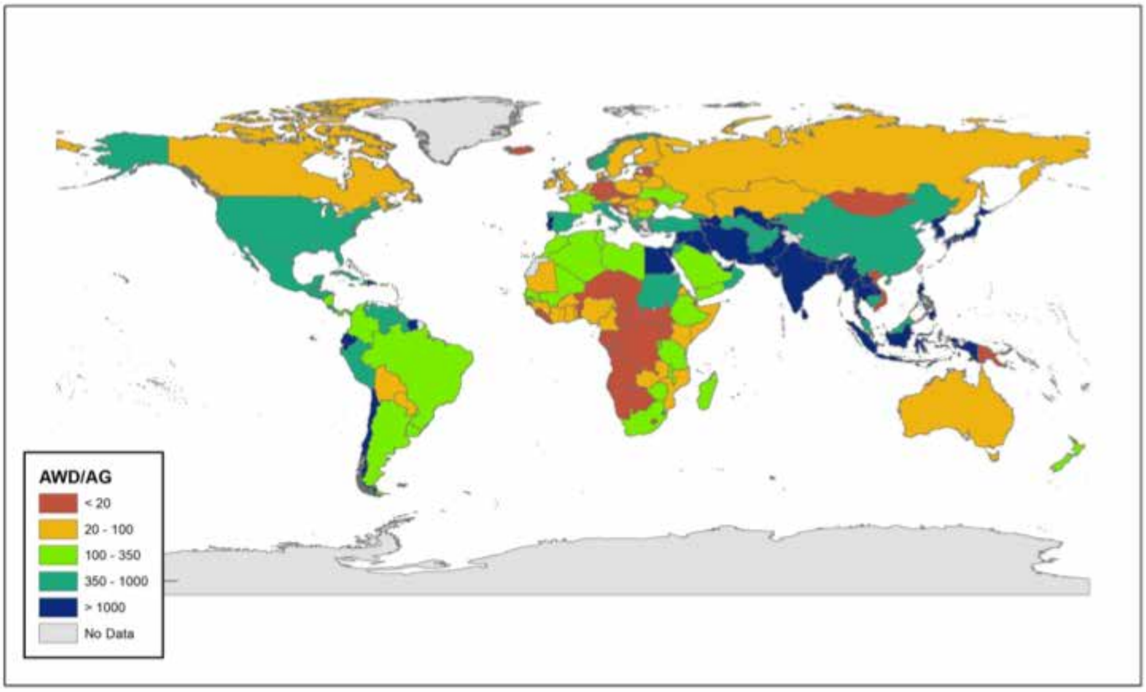
The challenges to feed the world in 2050 are well-known by now, and can, as a summary statistic, be captured as the task to increase global agricultural production to cater to a global demand which is projected to increase by 50 percent between 2012 and mid-century (FAO, 2017a). External inputs must grow at about the same rate while decreasing returns in productivity can be compensated for or possibly surpassed by further efficiency gains. This document focuses on the management of water for agricultural use, which constitutes the largest share of total water demand for many countries. Figure 1 gives a global overview of the share of agricultural water demand over total water demand, showing that East Africa, the Arabian Peninsula, the Middle East, the Eastern Part of Latin America and South Asia allocate more than 85 percent of their water withdrawals for agriculture. In large parts of Central America, Southern America as well as North Africa, and parts of Southern Africa agriculture claims between 70 and 85 percent of water withdrawals. In the latter countries, a severe competition is observed between water demand in the agricultural and industrial sectors and the recent rise in household demand. Clearly, in certain countries, large efficiency gains can still be realized by limiting losses and by introducing water-reducing irrigation technologies. Even when large efficiency gains can be possible (see Figure 2), it is fair to assume that agricultural water demand will continue to represent the largest share of total water demand and is expected to grow further, especially in the developing world.

FIGURE 1
The share of agricultural water demand over total water demand



Source: FAO, Land and Water Division, 2018

FIGURE 2
Agricultural Water Demand (000 m^3) by Agricultural Area (ha)



Source: FAO, Land and Water Division, 2018.

The World Water Development Report (UNESCO, 2018), the demand for agricultural water is expected to increase by a third. Projections are, as usual, fraught with uncertainty. In this case, even more so, since climate change and land cover change can amplify or moderate future water demand (Dieguez and Paruelo, 2017). For instance, climate change can increase (e.g. through more intense precipitation) or reduce average water discharge (through an increase in evapotranspiration). Higher temperatures can lead to an earlier onset of snowmelt, while the expansion of cultivated areas and reduction of water holding capacity (soil sealing) can increase run-off volumes. In particular, the local impact of climate change is expected to be more pronounced as shown by the evidence displayed at the watershed level (Van der Esch *et al.*, 2017).

It follows that agricultural water supply will have to increase in order to meet the requirements of an agricultural system that has expanded its cultivated area, and has to produce higher yields in a volatile climate so as to meet the more diversified demand of a world with higher incomes and higher purchasing power. Water scarcity, already prevalent in many regions of the world, will become more widespread and prominent. Treatment of wastewater, large-scale desalination, and transport over large distances are options to increase supply in principle, but may not always be locally feasible or affordable.

Under a business as usual scenario, an additional supply of water, which often entails increased extraction of water, will greatly strain the existing ecosystems. Water supply will have to become more productive, most likely through the development of grey infrastructure to meet increasing water demand. At the same time, it has to be realized that conventional interventions based on grey infrastructure[1] have compromised the various ecosystem services that are required for stable water flows. In order to meet current and future demand for both water and a sustainable supply of ecosystem services, water management should make the best use of efficiency and productivity improvements at all levels involved, coupled with demand management and options beyond water domain (Unver *et al.* 2017), and transition to a new paradigm based on the premise that ecosystem functionalities should be preserved and nurtured rather than exploited and compromised. Specifically, the adoption of so-called Nature-Based Solutions (NBS) and the related protection and sustainable development of ecosystems could enhance a resource efficient and competitive circular economy, once well-considered and appropriate interventions are being established.

Indeed, NBS have the potential to underpin a sustainable water management strategy for agricultural purposes, as shown in an increasing number of cases (Niemi *et al.*, 2007; Talberth, *et al.*, 2013; IFRC, 2012; Turner *et al.*, 2007; Nesshöver, 2017). The potential for NBS projects may be much larger still, as the New Climate Economy (2016) argues. The global economy would require about US$90 trillion in green infrastructure[2] over the next 15 years, while currently about US$3-4 trillion per year is spent (NCE,2016). Such massive investments have to take place under carefully formulated conditions that seek to simultaneously optimize water supply and to preserve the integrity and value of the ecosystem at stake. To align these conflicting goals, the key issues are in finding a way to identify the pre-conditions required to create an enabling environment for NBS and how to conduct its successful implementation.

This discussion paper argues that both questions can be addressed through a two-pronged approach. The first task is a comprehensive valuation of the services that the ecosystem

[1] Grey infrastructure refers to engineering projects that use concrete and steel.

[2] Green infrastrure depends on plants and ecosystem services

provides. This is, in principle, the basis for (economic) decision making. Yet, it is also well-known that the complete range of use and non-use values is difficult to determine in monetary terms. This is true, in particular, for large and indivisible ecosystems that require special natural resource management and an adequate social fabric for its organization and supervision. Therefore, a second pillar is needed to complement the imprecise and incomplete valuation process and to facilitate the implementation steps. The basic insight is that the management of ecosystems for NBS should cut across the whole range of scientific fields involved (it should be an interdisciplinary approach) and should integrate scientific and case-specific knowledge with experience and practice in problem-solving (i.e. it also is a transdisciplinary approach). This means NBS involve all relevant stakeholders, ranging from governmental participation to coordinating higher levels of involvement of the custodians at the grass-roots level. This requires mutual trust, willingness to learn, patience, and the ability to adapt to the requirements of circumstances (Mander *et al*., 2017).

This document is organized into five sections. Section 2 characterizes NBS interventions in the agricultural water management context. Section 3 discusses the valuation of natural resources and offers guidelines for the management of ecosystems of NBS interventions. Section 4 summarizes lessons learned based on the success and failure of the various NBS case studies presented. Finally, Section 5 includes a synthesis of the paper with conclusions.

2. NBS – a new paradigm for water management

Historically (e.g. Bossio *et al*., 2008) water management practices in the agricultural sector were viewed as a driving force behind natural habitat degradation, purposefully obstructing the functioning of ecosystem services (Coates *et al*., 2013; Dale and Polasky, 2007). These controversies became manifest, for example, in the management of wetlands (Finlayson *et al*., 2013), rivers and lakes that on the one hand provide ecosystem services by supplying water for agriculture, while on the other hand, the quality of water bodies is affected by high concentrations of agrochemicals. Yet, there is a growing understanding that interventions that sustain or improve the state and quality of ecosystems are also beneficial for agricultural development and agricultural water management. Moreover, it is anticipated that in the next few decades- the agricultural sector will remain the dominant user of water. NBS are potentially a powerful strategy to transform the agricultural sector to be both a beneficiary and custodian of ecosystems. Indeed, NBS adoption provides opportunities to organize the nexus between agriculture–ecosystem–water to support sustainable food production and reaping the benefits of a well-functioning ecosystem.

2.1. DEFINING NBS AND CLASSIFYING INTERVENTIONS

In principle, NBS can mimic natural processes and build on fully operational water-land management concepts that aim to simultaneously improve water availability and quality, and raise agricultural productivity. As such, NBS comprise closely related concepts such as improved water use efficiency, integrated watershed management, source-to-sea initiatives, ecosystem approaches, eco-hydrology, agroecology and, green and blue infrastructure[3] development.

2.1.1 Compatible concepts, tools, approaches, and terminology

There are many concepts available that either align or can be comparable to the definition and scope of Nature Based Solutions (NBS) (see Box 1). In principle, NBS aims to contribute to the improved management of water resources at both the micro- and macro levels. NBS can involve conserving or rehabilitating natural ecosystems and/or the enhancement or the creation of natural processes in modified or artificial ecosystems[4]. Moreover, they support a circular economy that advocates greater resource productivity while reducing waste and avoiding pollution through reuse and recycling processes. NBS are consistent with numerous religious and cultural beliefs that advocate equity between man and nature. Although NBS are based on sound science and economics, they may represent a bridge between traditional and modern paradigms. NBS have a tendency to be in harmony with customary laws and local and traditional knowledge that are consistent with the human rights-based approach for water resources.

The inclusive character of the NBS concept has both strengths and weaknesses. There is, for example, no straightforward distinction between NBS and other human-induced management of ecosystem services. NBS is also interpreted as a mutually supportive approach for integrated water management that combines ecological and grey infrastructure (Mander *et al*., 2017). Moreover, there is a danger that the wide coverage of ecosystem concepts by NBS creates multiple interests for different stakeholders whereas only a few goals can be met simultaneously. To address these concerns and to reflect the inherent heterogeneity and complexity of the interaction between NBS and ecosystem services, Eggermont *et al*. (2015) suggested three NBS typologies that clarify trade-offs between the degree of engineering and the delivery of ecosystem services for the stakeholders involved:

These typologies should not be considered as a static representation of possible NBS interventions but are dynamic benchmarks for many hybrid NBS that exist along the gradients used, enhancing their flexibility and problem-solving capacity. For example,

NBS TYPOLOGY	
Type 1	None or minimal intervention in ecosystems. This type maintains/ improves delivery of ecosystem services of preserved ecosystems. This NBS incorporates areas where people live and work in a sustainable way including nature conservation and national parks.
Type 2	Partial interventions in ecosystems. This type develops sustainable and multi-functional ecosystems and landscapes that improve delivery of selected ecosystem services. This type of NBS are strongly connected to benefitting from natural systems agriculture and conserving the agroecology.
Type 3	Inclusive intervention in ecosystems. This type manages ecosystems in intrusive ways and includes full restoration of degraded or polluted areas using grey infrastructures.

[3] Blue infrastructure combines green spaces with good water management. Blue infrastructure ensures that buildings and spaces promote healthy and sustainable living environments.

[4] WWAP (United Nations World Water Assessment Programme)/UN-Water. 2018. The United Nations World Water Development Report 2018: Nature-Based Solutions for Water. Paris, UNESCO.

BOX 1

Concepts aligning to NBS

The **Ecosystem Approach** focuses on scientifically based integrated management of land, water and living resources to promote sustainable use of natural resources in an equitable manner. It encompasses specific to essential processes of the biological organization. It embodies the human aspect thus considering human diversity as an integral component of the ecosystem (CBD, acc. 26 July 2018).

The **Wise Use of Wetlands** has been defined by the Ramsar Convention on Wetlands as "the maintenance of their ecological character, achieved through the implementation of ecosystem approaches, within the context of sustainable development" (Ramsar Convention, acc. 27 July 2018).

Ecosystem-Based Management focus on the conservation, sustainable management and restoration of ecosystems. This approach recognizes the vast array of interactions within an ecosystem, involving humans. It considers resource trade-offs to protect and sustain diverse and productive ecosystems and services they provide. (UNEP/GPA, 2006). Environmental Flows consider the management of the quantity, timing, and quality of water flows below a dam, with the aim of sustaining freshwater and estuarine ecosystems and the human livelihoods that depend on them (International Rivers, acc. 27 July, 2018).

Green Infrastructure is a strategically planned network of natural and semi-natural areas that are designed to deliver ecosystem services. These areas provide opportunities for green jobs and enhance biodiversity. Green infrastructure provides environmental, economic and social benefits through natural solutions and reduces dependency on grey infrastructure (EU Environment, acc. 27 July, 2018). Ecological Engineering is defined as the design of ecosystems for the mutual benefit of humans and nature. It involves the restoration of ecosystems that have been disturbed by human activities and the development of new sustainable ecosystems comprising both human and ecological values (Mitsch, 2012).

Agroecology has been defined as "the application of ecological science to the study, design and management of sustainable agriculture". It creates diversified agroecosystems that mimic natural systems as closely as possible to enhance sustainable production and self-reliance (FAO, 2018a).

Globally Important Agricultural Heritage Systems are landscapes formed through coevolution of humankind and nature. They combine agricultural biodiversity, resilient ecosystems and a valuable cultural heritage. Moreover, they provide multiple goods and services, food and livelihood security for millions of small-scale farmers. These sites have emerged over centuries of cultural and biological interactions, representing the accumulated experiences of rural people (FAO, 2018b.)

Ecosystem Based Adaptation (EBA) uses biodiversity and ecosystem services as an entry point for development of adaptation strategies to climate change. EBA includes sustainable management, conservation and restoration of agriculture, forestry and fishery related ecosystems. EBA is cost effective and generates social, economic and cultural co-benefits (FAO, acc. 27 July 2018).

constructed wetlands involve a type 3 intervention that subsequently can be managed as a type 1. Source-to-sea concepts (e.g. Granit *et al*., 2017), for example, will apply type 2 and type 3 interventions in order to restore natural vegetation and control surface flows for agricultural production.

The openness of the NBS concept can also create an inclusive environment. Potschin *et al*., 2016 suggested the consideration of wider definitions of NBS concepts as a flagship term that offers incentives for public-private partnerships and citizens to integrate natural and ecological values (e.g. biodiversity) in the planning of prospective scenarios. These scenarios would address wider societal challenges including resource degradation, climate change, and social equity.

All-inclusiveness of the NBS term also recognizes the value of regulations and customary laws of indigenous people that prescribe sustainable management of the common resources like sharing of drylands by nomadic pastoralists or joint management of fishing grounds by fishermen on inland lakes. Indeed, these institutions form an epitome of sustainability (e.g. Desta *et al*., 2004; Salpeteur *et al*., 2017; Olomola, 1993) that unrelentingly depend on a judicious set of rules that are instrumental in shared ecosystems management. The paradigm of NBS interventions also resonates with the natural resource management of indigenous people who combine conservation of ecosystem services with the preservation of the aesthetic beauty of the natural landscape and biodiversity. These ancestral agricultural systems have been recognized by FAO's Globally Important Agricultural Heritage Systems (GIAHS) programme as systems that offer rich knowledge base on sustainable agricultural practices for a better and more efficient use of natural resources (FAO/GIAHS, 2018a). Moreover, NBS can achieve substantial gains in human well-being when related ecosystem services are mainstreamed with poverty reduction strategies (ESPA, 2018; MacKinnon *et al*. 2011). The International Union for Conservation of Nature (IUCN, 2012) frames biodiversity and reinforcement of communities' rights over natural resources at the heart of NBS showing that an alignment of environmental sustainability pathways is a requirement and certainly not a constraint to achieving higher economic and social development (Burek *et al*., 2016; Scholes and Biggs, 2004). NBS also offer cross-cutting solutions to meet the Sustainable Development Goals (SDGs). NBS contribute to SDG15 by protecting the sustainable use of terrestrial ecosystems that provide favorable conditions for water-related ecosystem services that directly underpin poverty alleviation efforts (SDG1), the zero hunger initiative (SDG2), ensure water and sanitation services (SDG6), and mitigate negative effects under climate change conditions (SDG13).

2.2 NBS AND AGRICULTURAL WATER MANAGEMENT

Water availability considering both its quantity and quality, at the correct time and place, is an important ecosystem service to agriculture and food security. Understanding the underlying mechanisms of the ecosystem, and its influence on water availability in terms of volume and quality for agriculture and food security provides the guidelines for targeted NBS interventions. Our focus is on NBS interventions that enhance water-related ecosystem services for the sustainable development of agricultural initiatives whilst reducing external impacts on water and land resources (Hattingh *et al*., 2007). NBS activities should ensure sustainable development of ecosystems that provide lasting services for current and future generations (Sood *et al*., 2017).

NBS can serve agricultural water management by regulating the movement, storage, and transformation of water, including its quality (Acreman and Mountford, 2009). For

FIGURE 3
SDG's related to NBS

example, in South Africa, after rehabilitating the thicket biome[5] in the Baviaanskloof-Tsitsikamma and uMngeni catchments (Mander *et al.*, 2017), canopy interception increased and soil functionalities showed improvement in terms of infiltration, conductivity and soil moisture retention. These regulatory mechanisms have a significant positive impact downstream by decreasing flood intensities and increasing base-flow that, during the dry season, resulted in sustained and reliable flows. Ecosystem functionalities are often restored by combining natural and infrastructural modifications in the landscape. The World Business Council for Sustainable Development (WBCSD, 2018), reported that a blend of tree planting and construction of pits and earthen banks preserved substantial amounts of water and re-established the recharge rates that fed depleted aquifers in the Puebla Tlaxcala Valley, Mexico. An interesting Type3 NBS example is that of constructed wetlands in Europe and the USA (EPA, 2000) that offer ecosystem services to improve water quality by filtering water, trapping suspended solids by vegetation and immobilizing pollutants that are either taken up by water vegetation or deposited. Wetlands provide high-level water treatment techniques like deposition, nitrification and anaerobic digestion of organic wastes and microbial suites (Horwitz, *et al.*, 2012). Water treatment mechanisms also hold for the processing of excess of nutrients, derived from agriculture that are, for example, absorbed by wetland soils or, for organic nitrogen, converted by micro-organisms into inorganic chemical structures that are taken up by plants.

These are just three of many examples of (improved) ecosystems serving water management objectives. A synopsis of over 20 cases (section 4) constitutes the basis for an assessment of the possible reasons for success and failure of NBS. In an ideal world, such an assessment hinges on a (monetary) valuation of services provided by the ecosystem, including the valuation of the ecosystem itself, as an entity that is worth preserving. In practice, however, proper valuation techniques are difficult to implement or unavailable to the decision-makers and as a result many NBS interventions are often based on ad-hoc decisions. Since this paper strives for (and presents) a more encompassing framework of valuation and implementation of NBS, a brief review of the theory and practice of the valuation of natural resources and the required conditions for its implementation follows in the next section.

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[5] The subtropical thicket biome in Southern Africa occurs in a wide range of annual rainfall regimes and on poor and fertile soils. Its vegetation varies from shrubland to low forest with many evergreen and succulent trees and shrubs. Source: https://pbhslifescience.wordpress.com/2015/09/07/biomes-of-south-africa-thicket/.

Photo: ©FAO/Giuseppe Bizzarri

3. Challenges for implementation of NBS policies

This section will discuss the valuation of natural resources, the principles, and techniques to allocate a price to an ecosystem service and present a transdisciplinary, multi-stakeholder approach to ecosystem management that informs NBS implementation.

3.1 THE VALUE OF THE ENVIRONMENT[6]

One way for policymakers to make informed decisions about NBS interventions is to value the changes in related ecosystem services in monetary terms. This facilitates a comparison among NBS with other interventions and facilitates the selection of policies that yield most benefits to society. Furthermore, allocation of a price to ecosystem services gives a signal of water scarcity providing an incentive to avoid overexploitation and degradation while warranting a sustainable use of water/natural resources and preservation for future generations (Box 2). As is the case for pricing commodities, ecosystems services can, in principle, be assigned a value that reflects water scarcity and utility in terms of human satisfaction.

[6] This section draws on Keyzer *et al.*, 2009.

A healthy ecosystem can provide a variety of crucial services for public goods, such as clean water, nutrient cycling, climate regulation, and food security services that contribute directly or indirectly to human well-being. Yet today, many ecosystems are in decline; this is of particular importance to agriculture, which depends on ecosystem services.

BOX 2
The values of ecosystems

Ecosystems contribute in different forms to NBS interventions. Direct use values refer to ecosystem services for consumptive purposes like fresh drinking water and sanitation. Indirect-use values are associated with intermediate inputs for production of final goods like processes of water purification and waste assimilation. Amenity values refer to, for example, admiring the scenic beauty of rivers through landscapes. Option values reflect unexploited potential of environmental services that can be used in the future, for example to clean water, while responsibility to preserve ecosystem quality for future generations, the natural heritage, is expressed in the bequest value.

Loss of healthy ecosystems will seriously affect the production of food, both today and in the future. Payments for ecosystem services (PES) or incentives for ecosystem services (IES) are economic instruments designed to provide positive incentives to users of agricultural land and those involved in coastal or marine management (Box 3). These incentives are expected to result in the continued or improved provision of ecosystem services, which, in turn, will benefit society as a whole.

BOX 3
PES and IES

Payment for Ecosystem Services occur when beneficiaries or users of an ecosystem service make payments to the providers of that service (Fripp, 2014).

Incentives for Ecosystem Services (IES) is a tool that can be used to maintain or improve the flow of ecosystem services, while rewarding the managers of that ecosystem service (Patterson, *et al*, 2017).

The management of ecosystems has several features that require careful consideration and that may affect or compromise the valuation of ecosystem services. First, there is the issue of the so-called negative externalities: a person who receives the benefits of natural resource use does not necessarily pay for the costs imposed on others. Soil erosion causing sedimentation of lakes and mine pollution contaminating surface and groundwater resources are two frequently occurring negative externalities that go unpaid. This is commonly expressed by stating that the polluters-pay-principle is violated, and the valuation process is incomplete since the social costs due to the pollution are not covered.

Second, many ecosystems are in the public domain and their benefits cannot be restricted to the owner(s) only. The ecosystem is said to be non-private and non-excludable.

A special case is where the benefits are also considered to be rival, which means that consumption of ecosystem services diminishes the capacity of others to enjoy the same benefit. This creates a particular form of externality known as the Tragedy of the Commons (Hardin, 1968). Benefits of additional use of these jointly shared resources accrue to the individual while the costs are born by the entire group. Overgrazing is the classical example: the costs of forage consumption from communal rangeland seem small to the individual because it is distributed among all other users. Rivalry among fishermen that cumulate in overfishing of inland lakes is another example.

These particular properties of ecosystems are well understood by now, theoretically, and institutional tools have been developed to remedy them. For instance, the government can impose a tax to bring the polluting activity back to the socially desirable level. Common property resources are often managed collectively, as shown by Ostrom (1990), even under a set of informal and unwritten rules.

3.2 TECHNIQUES OF ECOSYSTEMS VALUATION

In general, the valuation of ecosystem services is not an easy task, because ecosystems like watersheds, rain forests and inland lakes are not traded in markets and their value cannot be derived directly from a demand-supply relationship. Consequently, techniques to value the environment are usually of indirect nature, and can be classified according to the basis of the monetary valuation: market-imputed, surrogate market or non-market-based.

NBS interventions for agricultural water management partly rely on market-based approaches that invoke the price mechanism for end-users (farmers) of the ecosystem services. For example, water prices are imputed from marketed commodities like agricultural products, timber and drinking water for livestock, each providing an end product with a functioning market. Production function analysis and defensive expenditures are two other examples of market-based approaches. Production

BOX 4

Why is it difficult to implement NBS?

i. Characteristics of ecosystems relate to non-excludability issues in water management:

- Lumpy indivisible water bodies (aquifers, inland waters)
- Distributed water flows require ample space
- Interconnectedness makes all places equal
- No ‘closing down’ if unprofitable
- Difficult to protect from unpaid use

ii. Consequences of non-excludability

- Unpaid use of ecosystem services
- No price signals of scarcity

iii. Inadequate pricing results in:

- Free rider’s behavior (‘Tragedy of the Commons’)
- No incentive for production of ecosystem services
- No role for ecosystem custodians

functions use detailed process knowledge to identify the marginal contribution of the ecosystem service to a marketed commodity, for example, to determine the added value of water to crops (e.g. Archaya and Barbier, 2002; Freeman, 2003). For example, Albersen *et al.* (2003) show that downstream economic activities (e.g. agricultural yields) can be related to the economic value of upstream water flows. Concerning defensive expenditures, these equal the cost of maintaining an ecosystems' productivity by protecting it against pollution and degradation (e.g. Tiezzi, 2002). Despite this, there are many ecosystem services that cannot directly be related to market prices and a surrogate market or non-market based approach has to be designed.

Surrogate markets can be introduced through either one of two pricing techniques. The hedonic pricing method assigns a price to an ecosystem based on the comparison of the values of houses that have otherwise similar conditions but differ in environmental characteristics (e.g. Taylor and Smith, 2000). The travel cost method values a recreational site by the economic costs that travelers incur for a visit (e.g. Pendleton and Mendelsohn, 2000).

Finally, there are non-market-based techniques that elicit information from individuals based on both their willingness to pay for the improvement of ecosystem services (e.g. Alfarra, *et al.*, 2013) or to be compensated for the degradation of the ecosystem. Two methods are commonly used. First, contingent valuation uses surveys and interviews to ask for the willingness to pay for environmental services (e.g. Kolstad, 2000). Second, the conjoint stated preference method uses experiments to estimate intended financial contributions to the environment by ranking various options that represent levels of non-marketable services (e.g. Roe *et al.* 1996).

The various methods of ecosystem valuation come with drawbacks. The production function analysis needs detailed process knowledge and a vast empirical base that is often not available or has to be realized against high costs. Criticism on the surrogate market methods refers to personal subjective interpretation with respect to the subject that is valued, while a correlation with other non-ecosystem values cannot be excluded. Stated-preference methods have the disadvantage that respondents give strategic answers while commitments to pay the price are never tested. In conclusion, the experimental designs in the stated-preference may not be suitable to represent actuality. Hence, relying on these less accurate pricing techniques might weaken NBS with respect to alternative scenarios.

Since pricing strategies are difficult to implement, they are usually combined with, or even replaced by, regulation and quantitative restrictions. A strict conservationist protective measure is then the most far-reaching. Strict conservationism or 'strong sustainability' measures bans all use and ensure the functioning of ecosystems that are considered to be essential to human well-being for current and future generations. Under a regime of strict conservation current levels of ecosystem quality are stringently maintained (Brekke, 1997). Of course, less strict conservation is possible, and indeed common, which allows for limited use; this can be accommodated and governed by licensing schemes and user quotas as instruments.

Quantitative restrictions are powerful to prevent ecosystem exhaustion, but are economically less efficient and require expensive monitoring systems. This may be remedied by establishing private property rights over ecosystems. This privatization strategy (which may involve collective ownership) solves the excludability problem, by definition, but is hard to align with the inherent characteristics of large ecosystems. The very potency of such large ecosystems can only be derived from the use of their full physical extent.[7] The related reason is that conservation of natural resources requires concerted action at various levels. For example, high set-up costs of ecological interventions for degradation control should be borne by all stakeholders; higher administrative levels should be responsible to levy contributions. Finally, when distributing property rights social equity issues come to the fore, especially when richer and powerful groups benefit from the new situation while the poor are denied access to earlier shared ecosystems.

3.3 MULTI-STAKEHOLDER ENGAGEMENT AS A REQUIREMENT FOR NBS IMPLEMENTATION

Valuation and taxation, assignation of property rights, regulation and quantitative restrictions offer a toolkit on how to govern ecosystems. Yet, since interventions necessarily require a trade-off between the integrity of the ecosystem and the required effects demanded from ecosystem services, a structured and more encompassing process is needed, involving all relevant stakeholders, for a successful implementation of NBS.

Management of ecosystems for NBS is too complex to be dealt with adequately with the concepts and methods of a single discipline. Hence, the knowledge base for NBS interventions should transcend their own disciplines and cut across a broad range of established academic fields (inter-disciplinary) as well as beyond the boundaries of the scientific community (trans-disciplinary) integrating scientific and case-specific knowledge with experience and practice in problem-solving. Moreover, to assure that NBS are supported by well-functioning ecosystems they should be grounded in society and involve all relevant stakeholders from governmental participation for coordination at higher levels, developing policies and legislation to custodians at a grass-root level that are directly responsible for the state and functioning of ecosystems. This requires confidence, mutual trust, willingness to change, ability to adapt to new circumstances and endurance (Mander *et al*., 2017) while addressing the challenges to functioning of multi-stakeholder processes (HLPE 2018), the critical role of a neutral convener and broker (Kalas et. 2017) and inclusion of all stakeholders, particularly the most marginalized to overcome power asymmetries (Kalas, 2007; Rioux and Kalas, 2017, Kurbalija and Katrandjiev, 2006; Kalas, 2007; Saner, 2007). Jointly, stakeholders should design monitoring systems that can be used to reward good stewardship, penalize neglect, and sustain the transfer to the next generations. At the heart of the process is the importance of a multi-stakeholder / multi-actor platform conceived and defined together with stakeholders to create the space for dialogue, consensus building and joint-decision-making (Kalas et. all, 2017). Additionally, the paper capitalizes on lessons learned from common pool resources (CPR) management (e.g. Ostrom, 1990; Dietz *et al.* 2003). Specifically, there is congruence with ecosystems for water management, in terms of setting system boundaries and taking into account diversity. Moreover, the multi-stakeholder approach in CPR management gives useful guidelines to shape social processes that can be adopted for NBS interventions. These guidelines secure full participation of local users, encouragement of collective action, the right of groups to organize, and, finally, the establishment of conflict resolving institutions. If these institutions fail, the prevailing ecosystems can be seriously threatened in the long term and wreak havoc upon involved users and communities. Transparency of the organization and jointly developed tools will be helpful to coordinate concerted actions.

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[7] For instance, restricting accessibility by partitioning drylands seriously undermines the strategy to avoid dry spells through migratory routings; interconnected water flows in bounded watersheds cannot be controlled without affecting downstream users.

The conclusion is that ecosystem properties demand that inter- and transdisciplinary approaches and multi-stakeholder engagement are at the very heart of NBS implementation. A similar conclusion to adopt a transdisciplinary approach has been reached in the OpenNESS project[8], (Jax *et al.*, 2018). The basic rules for managing common property resources (as formulated in McGinnis and Ostrom, 1992) can also be seen as a practical implementation of this approach. In the next section, several case studies are analysed. Lessons learned to suggest concrete policy guidelines and roadmaps for upscaling best practices in NBS for agricultural water management and food security while minimizing environmental impacts.

[8] OpenNESS aims to translate the concepts of Natural Capital (NC) and Ecosystem Services (ES) into operational frameworks that provide tested, practical and tailored solutions for integrating ES into land, water and urban management and decision-making. It examines how the concepts link to, and support, wider EU economic, social and environmental policy initiatives and scrutinizes the potential and limitations of the concepts of ES and NC.


Photo: ©FAO/Ami Vitale

4. NBS case studies; what can be learned?

This section evaluates various case studies that were identified as NBS interventions. The NBS case studies were selected for their contribution to water management interventions. Our aim was to learn from successful and failed experiences and to identify possible causalities among factors that characterize the implementation of NBS. However, in the short time available for the literature survey serious bias in the reporting of success-stories was found whereas failed NBS interventions were difficult to find. Hence, this data set is not statistically representative. This being said, the paper does explore the associative patterns that indicate and explain the possible outcomes of NBS success rates. Factors discussed in the evaluation are:

- identification of stakeholders and beneficiaries
- prevailing degradation process
- assessment of stakeholder involvement
- the degree of transdisciplinarity
- typology of NBS intervention (See 2.1)
- rewarding schemes for custodians
- stability of institutional collaboration

- stability of financing, and
- success or failure of the NBS.

The Rubrics presented in Table 1 give a scoring guide to evaluate the NBS interventions.

TABLE 1
Rubrics for NBS evaluation

Code	Transdisciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
--	Absence of transdisciplinary approach	Absence of rewarding schemes	No collaboration	Social and ecological NBS objectives were not achieved
-	Transdisciplinary approach present but implementation unsuccessful	Presence of rewarding schemes but unsuccessful implementation	Some collaboration	Either social or ecological NBS objective was achieved
-+	Transdisciplinary approach present with some results	Rewarding schemes present with some results	Collaboration established with minor results	Part of the social and ecological NBS objectives were achieved
+	Transdisciplinary approach successful; clear involvement of transcendence stakeholder	Rewarding schemes successful; payments assure NBS objectives	Collaboration successful; alignment of activities	Social and ecological NBS objectives were achieved successfully
++	Transdisciplinary approach very successful; stakeholders of transcendent disciplines fully participate in NBS process from design to implementation	Rewarding schemes very successful; payments assure NBS objectives and encourage other PES initiatives	Collaboration very successful; alignment of activities and establishment of sustainable relationships	Social and ecological NBS objectives were achieved successfully and mutually strengthen each other

Section 4.1 briefly presents 21 selected case studies indicating the references consulted for this study, followed by an assessment that provides a summary of major findings (Table 2)

4.1 CASE STUDIES

C 1. Modeling potential hydrological returns from investing in green infrastructure in South Africa.

Main characteristics: Success, type 1.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
1	+-	--	--	+

The sustainable development of the South African economy and the well-being of its people are seriously affected by prevailing water shortages. Climate change, land degradation and an inherently semi-arid, variable climate are making it increasingly difficult for water service providers to deliver sufficient quantity and quality of water to meet South Africa's escalating demand. Investments in ecological infrastructure are rarely considered as a way of augmenting water supplies and improving water quality over the long-term. Hydrological modeling shows that protecting and rehabilitating ecological infrastructure could generate meaningful gains in water quantity in two important South African water supply systems, the Baviaanskloof-Tsitsikamma and uMngeni catchments. In a paired catchment experiment, the NBS was of thicket vegetation rehabilitation influenced the basin's hydrology positively as flood intensities decreased while base-flows and water availability increased in the dry seasons. Costs of NBS interventions are in the same range as grey engineering structures. For example, ecological infrastructure ranges from 1.67-4.67 Rands M^3, built infrastructure varies from 4.56-9.01 Rands M^3 and dams from R0.50 to 3.79 Rands M^3. Implementation of a monitoring network and research program will deepen the understanding of ecosystems and contribute to select the correct interventions (excerpts from Mander *et al*., 2017).

C 2. Izta-Popo - Replenishing Groundwater through Reforestation in Mexico

Main characteristics: Success, types 2 and 3.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2/3	+	+	--	++

The Puebla Tlaxcala Valley in Mexico hosts a Volkswagen production plant whose water demand exceeded natural water supply. The surrounding land would, in principle, replenish sufficient groundwater. Yet, deforestation, overgrazing, and fires severely affected the hydrological cycle of the area increasing runoff while reducing aquifer recharge. Together with the Comisión Nacional de Áreas Naturales Protegidas, Volkswagen developed a NBS related water infrastructure to restore ecosystem functionalities on the slopes of the Popocatépetl and Iztaccíhuatl volcanoes. To facilitate this, approximately 300 000 Hartweg Pines, a tree native to Mexico, were planted in 2008 on 300 ha of land located at an altitude of up to 4000 meters. To support pine growth nutrient concentration, the soil was amended with organic material. Additionally, pits and earthen dams were constructed to ensure that water sources were retained while trees were establishing. Over six years, 490 thousand trees were planted and 91 thousand pits and 430 earthen banks (dams) were installed (Figure 4). The restored ecosystem functionalities preserved water over 750 ha, enabling 1.3 MCM[9] /year of additional water; more than the plant consumes. The project capitalized on the local knowledge base to implement sustainable water use practices and transferred ownership of the restored land to participating local communities. A stakeholder buy-in from other organizations

FIGURE 4
Earthen banks/dams

Source: WBCSD (acc. 30 July 2018).

[9] Million Cubic Meter (MCM)

was an important factor in the projects' economic success. The project created widespread awareness within local communities and among students on the importance of environmental stewardship (Excerpt from WBCSD, accessed 2018).

C 3. The Saye River bank failure

Main characteristics: Failure, type 3.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
3	-	-	-	-

The downstream deposition of sediments and damage effects on the ecology of the Saye River Banks in Nigeria is caused by slope instability and erosion (Figure 5). As a result, agricultural development and the logistical operations of rural communities since 2008 were affected. Widening of the river resulted in a loss of floodplain affecting vast farmland areas as well as road foundations and railway bridges. Physical characteristics of the Saye watershed and its distributaries are changing rapidly due to accelerated erosion of the riverbanks. River depths became shallower at places and many off-takes were closed due to depositions of huge sediments loads. The intervention by the local government comprised engineering structures that should support natural slope formation in river banks. Yet, this top-down type 3 intervention of civil engineering structures is not feasible in the Saye River and its tributaries, where sandy, silty or loamy soil types prevail. As such, these structures cannot effectively solve the erosion problem nor revitalize the lost ecological life in the watershed. According to the local population, community involvements of the restoration efforts were absent nor were consultations with local people organized. Experts indicated that the widespread loss of indigenous plants like the wild palm and bamboo was a major cause of erosion and NBS interventions should concentrate on the restoration of original vegetation (Excerpts from Girku *et al*., 2017).

FIGURE 5
Saye River bank erosion, Nigeria

Source: Girku et al., 2017

C 4. Enhancing water security in Kenya using ancient methods of rainwater harvesting practices

Main characteristics: Success, type 2.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	+	--	--	+

The 884 thousand people that live in the semi-arid Makueni County in Eastern Kenya suffer from severe water and food insecurity. Subsistence farming is the prevailing form of agriculture (95 percent) with more than a stunning 60 percent of the population living in poverty (Excerpts from FAO, 2016a). Poor access to water in rural areas forces people, especially women and children, to walk for several hours to collect water. In 2002, UK's Excellent Development (Excellent, accessed 2018) and Excellent Development Kenya extended their activities to Makueni County with the NBS intervention through a sand dam (Figure 6) revitalization project and aa cost-effective rainwater harvesting technique. Self-help groups built sand dunes and introduced terraces, intercropping, crop diversification, seed banks, and agroforestry. Each community co-financed 40 percent of the project thereby creating ownership and long-term sustainability. Results were impressive. Sand dams supplied water non-stop to 91 percent of households, 958 thousand trees were planted and 1622 km of terraces extended. Agro-ecological techniques increased soil moisture and enabled small-scale irrigation to expand the growing season. A traditional knowledge sharing platform disseminated agro-ecological techniques through farmer-to-farmer field schools.

FIGURE 6
Sand dams store up to 30 million liters of water and create the opportunity to invest in ecological agriculture

Source: ©Excellent Development Ltd.

C 5. Water fund for catchment management, Ecuador

Main characteristics: Success, types 1 and 2.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
1/2	+-	+	++	++

The availability of clean water for people living in Ecuador's capital, Quito, is threatened by the unregulated expansion of agricultural production, illegal logging, and deforestation. With the support of the Municipality of Quito and the Quito Water Company, a water trust fund was created. The fund sponsors a multitude of NBS interventions targeted to watershed conservation activities and regeneration of viable ecosystem services (Figure 7) that should guarantee a clean and regular supply of water to the citizens of Quito. The major challenge was to obtain sufficient funding and political support, which took over seven years to materialize. Lack of scientific data regarding the provision of ecosystem services (only water balances have been constructed) hampered progress. Various water users were involved, including water utilities, electricity companies, and private users. The evolution of Ecuador's water trust funds highlights their ability to adapt to different socio-cultural and political conditions, including those that oppose the commodification of natural resources. As such, water funds

FIGURE 7
Farmer beneficiaries of the water trust fund

Source: ©FAO/Guiseppe Bizzarri

provide an innovative model for sustainable financing of watershed conservation activities in countries like Ecuador where privatization is not possible for either legal or cultural reasons (excerpts from Arias *et al*., 2010).

C 6. PES in the Ruvu watershed of the Uluguru Mountains in Tanzania

Main characteristics: Success, type 2

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	--	-	++

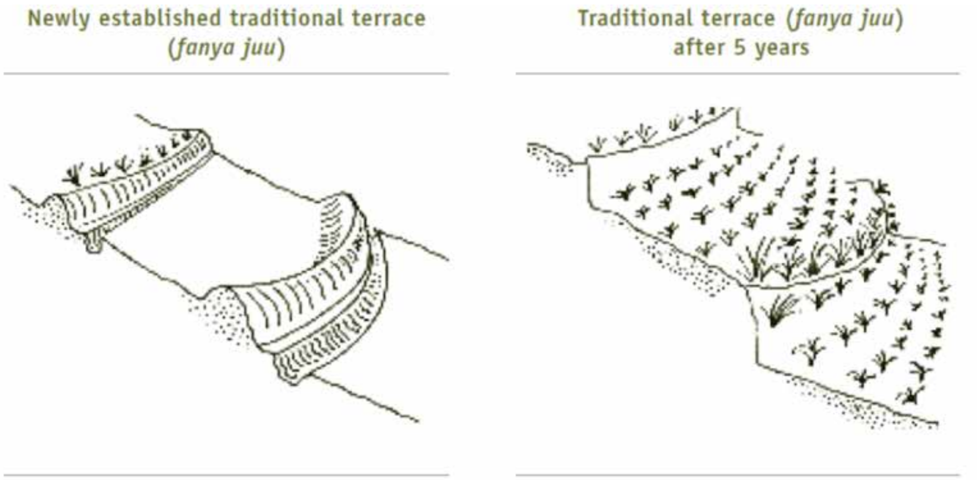
The Uluguru Mountains are a mountain range in eastern Tanzania that blocks moisture coming from the Indian Ocean. These mountains are characterized by wet east-facing slopes where overall annual precipitation exceeds 2000 mm. Rainfall is captured in a complex network of streams that jointly form the Ruvu River, which supplies water to over four million people in Dar-es-Salaam and to the major industries of Tanzania. About 150 thousand people live in the Uluguru Mountains in about 50 villages situated on the edge of the forested areas. In 2007, a hydrological assessment by CARE-WWF revealed an overall decrease in water quality due to a dramatic increase in sediment loading into the river. Meanwhile, significant fluctuations have been recorded in the annual volume of surface flows due to variations in the precipitation regime, as well as to increased runoff and an overall decrease in storage capacity. As a consequence, downstream water treatments were required due to a high siltation level of the Ruvu River while downstream water supply had to be rationed.

The restoration of the Ruvu's hydrologic services is linked to enhanced upstream land use management, which is strictly linked to poverty alleviation and livelihood improvements of this densely populated region. A PES scheme was initiated in the Ruvu River in Tanzania between downstream buyers (industry, sewerage plants) and upstream farmers. The PES incentivized farmer participation and assured their continuing commitment to the initiative.

Farmers received payments for adoption of agricultural practices that aimed to control runoff and soil erosion while improving crop production. A combined approach was implemented that includes structural (bench terraces and fanya terraces), vegetative (reforestation, agroforestry, and grass strips) and agronomic measures (intercropping crops with fruit trees, mulching and fertilizing with animal manure) to limit runoff, combat soil erosion, and increase soil moisture and productivity. The objective was to control soil erosion and simultaneously improve crop production, which is considered a Type 2 NBS intervention.

The implementing agency (CARE-WWF) in the Uluguru Mountains conducted a cost-benefit analysis showing that opportunity costs are key in the design of a PES scheme. This PES-type case study shows how estimating opportunity costs is a key factor in the design of PES schemes to ensure farmer participation. Long-term involvement of farmers is also necessary to meet the timescale requirements to restore the functionality of ecosystem processes (excerpts from FAO, 2011).

FIGURE 8
A combined approach was implemented that includes structural (bench terraces and fanya terraces)



Source: IIRR, 2008

C 7. Reducing land degradation in fragile micro-watersheds through integrated natural resources management in the upper basin of El Salvador's Lempa Riverthrough integrated natural resources management in the upper basin of El Salvador's Lempa River

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	-	++	++

Main characteristics: Success, type 2

The upper basin of the Lempa River in El Salvador suffers from increased drought while farmer practices of burning soil vegetation result in high erosion rates. An FAO/GEF (FAO/GEF, accessed 2018) project was linked to El Salvador's Family Agriculture Plan (FAP) in targeted micro-watersheds in the Santa Ana Department to reduce vulnerability and increase adaptive capacity to the adverse impacts of climate change of small-scale rural producers. The project is enabling stakeholders to mainstream climate change adaptation and disaster risk reduction priorities into "Fragile Micro-Watersheds Management Plans," while reducing land degradation and unsuitable land/water use through the integrated management of natural resources and the participation of small-scale rural producers. Through this project, a number of agro- and forest ecosystems were restored by training 55 technical staff from eight local institutions and Farmer Field Schools on sustainable soil management. Courses emphasized good practices, such as organic fertilizers, agroforestry, and cover crops management. Introduction of local agro-forestry systems resulted in increased vegetation cover. Families built rainwater collection harvesting systems for domestic use. The project was implemented with the support of local authorities and national agricultural extension agencies.

FIGURE 9
Farmers during "Farmer Field School" training

Source: IIRR, 2008

C 8. Qanat Irrigated Agricultural Heritage Systems of Iran

Main characteristics: Success, type 3

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	-	+	++

Farmers in the central desert of Iran have been using the traditional Qanat irrigation systems (Figure 11) as early as 800 BC (excerpts from GIAHS, 2014). Qanats have sustained food and livelihood security over millennia because they are a reliable source of water for traditional family farms in dry areas where agriculture and farming would be impossible otherwise. Kashan is home to some of the most impressive Qanats in terms of architecture, structure and indigenous knowledge. The Qanat is considered a traditional NBS that transports water through an underground channel system from aquifers to the surface for irrigation and household use. The Qanat system made the cultivation of a high number of species possible. Hence, biodiversity and genetic variation that is important for food and agriculture in a barren and sparsely vegetated area were possible. Indigenous and important biodiversity species, high-value crops, fruits, and trees have developed and survived thanks to Qanat technology (Figure 12). In total, about 32 types of various field crops and 20 types of fruits are produced in the region. Operation of the Qanat's is based on full participation of local water users that receive water according to the share of land owned. The construction and maintenance of the Qanat's rely on the well-organized participation of experienced labor and full cooperation among community members. As quoted in the GIAHS site, "Qanats represent a unique and inclusive system illustrating where indigenous knowledge in the sustainable management of land, water, and agricultural biodiversity is used" (GIAHS, 2014).

FIGURE 10
The Ardestan two-staged Moon Qanat, in Iran

Source: FAO/GIAHS, 2014

FIGURE 11
A forage crop farm on Qanat Qazi, Iran

Source: FAO/GIAHS, 2014

C 9. Horticulture production and food security of farmers in watershed communities in Burundi

Main characteristics: Success, type 2

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	-	+	++

The Kagera River basin is shared by Burundi, Rwanda, Tanzania and Uganda. The basin lies in a sub-humid agro-ecological zone with a bimodal rainfall, long rains from late February to May/June and short rains from late September to early December, providing a growing period of 90 to 200 days. Maintenance of the flow regime of the Kagera is vital for the preservation of Lake Victoria's water levels and the outflow to the Nile, while the riverine wetland areas have an important function in the deposition of eroded sediments and nutrients, hence, maintaining water quality. The transboundary area of the Kagera Basin is among the most important areas in Africa in terms of agro-biodiversity and food production. The diverse ecosystems and convergence of lowland (mainly western Guinea-Congolian) and highland (eastern afro-montane) species provide an array of habitats for multiple species of high global significance. Yet, the basin's land and freshwater resource base, associated biodiversity and populations whose livelihoods and food security depend on those resources, are under threat due to land degradation, declining productive capacity of croplands and rangelands, deforestation and encroachment of agriculture into wetlands. Climate change is associated with the disruption of rainfall which became unreliable and drought periods combined with extreme temperatures. An integrated ecosystems approach for land and water resources management was adopted in the Kagera Basin through a horticultural program to promote cultivation of vegetables that require small quantities of space, have a short growth cycle and are easily marketable. Anticipating climate change effects, high-yielding and drought tolerant varieties, organic fertilizer, small-scale irrigation, and mulching were applied. This is an example of a Type 2 NBS intervention. (FAO, 2017b).

FIGURE 12
FAO supports sustainable agricultural growth in Burundi through farmer field schools

Source: FAO, 2017b

C 10. Japan's Wasabi cultivation system

Main characteristics: Success, type 1.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
1	+	+	+	++

Wasabi, a highly valued native Japanese plant of the Brassicaceae family, is one of the main ingredients of traditional Japanese cuisine. The plant is cultivated in mountainous areas with high precipitation rates and springs that are used for its cultivation. The plant is originally from the Shizuoka region. Its cultivation began approximately 400 years ago, during the Keicho era (1596-1615) in the Aoi district of Shizuoka City.

The traditional cultivation of Wasabi is considered a Type 1 NBS intervention. Traditional cultivation methods use small amounts of fertilizers and do not apply agrochemicals. Through soil management, Wasabi fields maintain high water-holding capacities that prevent floods downstream. The wasabi production system offers a scenic landscape that is in harmony with natural ecosystems. For its production, villagers got organized and formed an association to agree on land and water resources use for wasabi fields (FAO/GIAHS, 2018b).

FIGURE 13
Wasabi field in Japan

Source: FAO/GIAHS

C 11. Using compost pits in Nepal

Main characteristics: Success, type 2

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	++	++	++

The Udayapur District in eastern Nepal consists of both plains and hilly areas, many of which are prone to flooding. Women are the major food producers in this region and are engaged in all stages of production, from planting to harvesting. Women's access to and ownership of land in Udayapur has increased over the years, enhancing their economic opportunities in farming.

Climate Change affected agricultural production, forcing men to migrate to find work elsewhere. As a result, women's workload in agriculture has increased significantly. Water sources have started drying up and unpredictable monsoons and floods have started to affect crop production.

A major problem facing farmers in this area is the increasing use of chemical fertilizers and pesticides in agriculture. These pesticides are damaging farmers' health and their environment. Chemical fertilizers are also causing negative impacts on soil structure and soil organic matter.

ActionAid Nepal supported women farmers' groups in the Udayapur District with the objective to promote sustainable agriculture and replace the use of chemicals in farming practices. Farmers received training in the management of organic soil matter, the health impact of pesticides and need to reduce dependency on external inputs. As a result, chemicals have been replaced by animal manure and organic pesticides. They were made aware of the importance of agro-ecological farming. This is considered a Type 2 NBS intervention. Other farmers adopted agro-ecological farming practices through compost pits water harvesting techniques, irrigation (drip irrigation) and the introduction of drought-resistant crops (excerpts from FAO, 2014b). Several farmers also invested in the combination of crop production and animal rearing as a way to increase livelihood options and economic alternatives. Farmer's rear chicken and goats for meat and manure, cows for milk, oxen for manure and field ploughing, and buffaloes for milk and manure. These animals provide an additional source of income from meat and milk. Their manure saves money that would be spent on chemical fertilizers and is a major source of plant and soil nutrients.

Every member of the farmers' groups contributes money to a collective savings scheme. The Village Development Committee also provides budgetary support to the community for training sessions on organic farming techniques. The process of organizing farmers into cooperatives and local groups has improved the solidarity of the community and improved the relationship with local agricultural offices and the Agriculture Service Centres.

C 12. Improving water efficiency in the irrigated drylands of Egypt

Main characteristics: Success, type 2

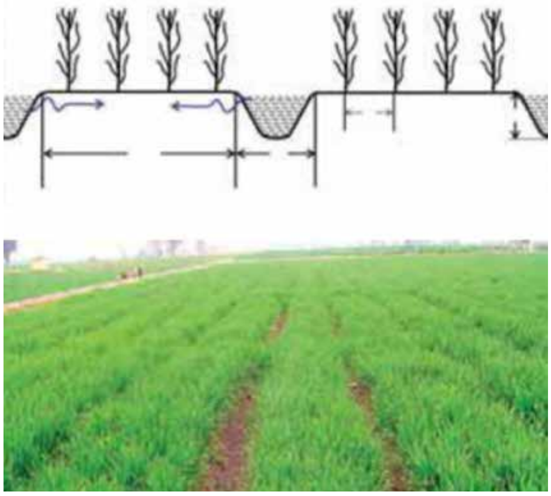
NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	--	-	++	+

Egypt's agriculture sector uses 80 percent of the available water resources. Due to the ongoing expansion of irrigated agriculture in Egypt and the challenges faced by dry climatic conditions, the focus is currently on the improvement of water efficiency.

The raised bed system is an improved surface irrigation strategy, which enhances water productivity and makes the application of water in irrigated systems more efficient. In this system, irrigation water is applied to the bottom of the furrows. In the raised bed system the furrows are wider than in the traditional one (see figure 15). Two furrows are merged, the width of the ridges is double as wide as in the traditional system.

A research project tested and validated the system between 2004-2008 for a sample of winter and summer crops (wheat, berseem, maize, cotton). The application of this technique with the main winter crops has shown that up to 25 percent of water could be saved, while crop production increased by 10 percent. Net benefits increased by 40 percent and reduced variable costs by 30 percent.

FIGURE 14
Raised-bed system



Source: FAO, 2018c.

Using raised-bed systems for surface irrigation in Egypt prevents high water losses and is considered as a Type 2 NBS intervention. The technology introduces improved crop varieties and agronomic practices. Agriculture productivity has increased by 15-25 percent while reduction of soil salinity and lower incidences of water logging are considered to be positive spinoffs (FAO, 2018c).

C 13. Groundwater management in Aweil East, Sudan.

Main characteristics: Failure, type 1.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
1	--	-	-	-

The political context of South Sudan has significantly shaped the groundwater management in the Aweil East Region, putting emphasis on emergency relief for access to water. Fragile institutions significantly hindered by the overwhelming presence of armed conflicts, fail to assure water supply while communities lack local capacity; dependency on aid organizations is high. Illustrative is the lack of clarity in water management rules on micro, meso and macro-levels. The ethnic/tribal violence that broke out in 2013 had a negative effect on sustainable development. The water crisis in Malualkuel Boma is a special case in point. The NBS intervention, in this case, study, refers to local boreholes financed by local authorities. Yet, these boreholes were unreliable and largely insufficient to cater to the water needs of the communities. Hence, women need to venture into an unsafe trek for three hours to get water and an additional three hours to walk back home. The alternative is to queue for a whole day at the hand pump for 20 liters of water, which is insufficient for a household for one day (excerpts from Murad and Ulveland, 2014; Reliefweb, 2007).

C 14. Water for Life and Sustainability Water Fund, Cauca Valley, Southwestern Colombia

Main characteristics: Success, type 2

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	++	+	++

Cauca Valley is Colombia's largest sugarcane producing region. The Nature Conservancy and its partners have been working to implement and refine an innovative Water Funds concept to secure freshwater for people living downstream in urban centers and other large water users (irrigation) in the region. The fund compensates those living upstream for conserving or restoring watershed headwaters (excerpts from The Nature Conservancy, 2013).

A Payment for Ecosystem Services (PES) model has been set up where sugar cane growers invest in a scheme that is used to promote land use change, fencing, and set-up of silvopastoral systems, forest enrichment, and restoration. Complementary grey infrastructure has been built. This intervention combines grey and green infrastructure and is considered Types 2 and 3.

Investors—the large water users—pay to an endowment fund (the water fund) whose earnings leverage public and private funds and benefit local communities. This self-sustaining funding mechanism supports efforts such as watershed conservation and habitat restoration and enables development of sustainable small businesses. In some cases, instead of endowment funds, there is a flow of constant revenues based on water users' contribution. Because of their intrinsic flexibility, water funds are well-suited to be replicated globally, which sets the stage for their application in a range of contexts and political realities.

Results have shown that growers benefit from the increased water supply, which safeguards long-term prospects of water-intensive agricultural activities. The scheme also resulted in enhanced flood risk management, reduced waste and promoted local entrepreneurship (Ramos, 2012).

FIGURE 15
Farmer in the Cauca Valley.

Source: FAO, 2018. ©Patrick Zachmann/Magnum Photos / FAO

C 15. Greening infrastructure to address water security in Lima, Peru

Main characteristics: Success, type 2/3.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
3	++	++	++	+

Lima, the capital of Peru, is a fast-growing desert city with 10 million inhabitants. The population pressure constitutes a significant burden on the surrounding environment and natural resources, in which 75 percent of tree cover has been lost (excerpts from Qin *et al*., 2016 in FAO, 2018d). As a result, the area suffered from increased droughts, floods and landslides (Barrett, 2017 in FAO, 2018d). The Peruvian government adopted in 2015 a law on 'Mechanism for Ecosystem Services Compensation' to guide and oversee the introduction of green infrastructure at the national level. The new law is an opportunity for the water sector to harmonize NBS with ongoing grey infrastructure projects. Gammie and de Bievre (2015) showed that a NBS that integrates existing grey with green infrastructure reduces dry-season deficits by 90 percent at lower costs than increasing grey infrastructure alone. Practices implemented are reforestation, pastoral reforms, and wetland restoration as well as other low-impact approaches such as rehabilitation of traditional 'amunas'[10] system. Funding is provided by Lima's water utility authority, which reserves 5 percent of its water bills (approximately US$110 million) to finance green infrastructure projects that should mitigate negative effects of climate change and reduce disaster risk. Local communities, governments, industries and NGO's in Lima launched a multi-sectoral platform to orchestrate conservation and restoration activities and to promote sustainable use of water resources (TNC, 2018). Lima water authority (SEDAPAL) is developing a novel green infrastructure master plan to enhance and complement grey infrastructure (SEDAPAL, 2016). Lima is pioneering a new generation of integrated water and landscape management, providing an example for other municipalities and countries to follow.

C 16. The Marikina Forest Watershed Integrated Resource Development

Main characteristics: Success, type 2

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	++	++	+

After the intensive floods in the metropole of Manila, the Philippines, caused by tropical storm Ondoy in 2010, the mayors of seven towns signed a memorandum of agreement to jointly implement a set of NBS to rehabilitate and reforest the Marikina watershed. The initiative was led by the Philippine Disaster Recovery Foundation which consists of a broad alliance of business organizations and non-governmental organizations. The specific objectives were to: a) reforest 34 percent of the watershed's degraded areas; b) establish a cooperation among various sectors to rehabilitate, protect

[10] Amunas are stone canals built in the Andes by the Wari culture between 600 and 1000 BC. Amunas capture water from rivers and let it infiltrate into rocks that fed year-round springs further (Pearce, 2015).

and restore the watershed; and c) reduce human-induced pressure on the watershed by providing alternative sources of income for local inhabitants.

The national government cooperated with this initiative by revising existing land and water legislation and developing a plan to address the expected negative impacts of future climate change in the Marikina watershed. Moreover, the upper Marikina watershed was declared a protected area (excerpts from FAO, 2016b).

FIGURE 16
Assisted Natural Regeneration (ANR) Approach to Forest Restoration in the Philippines

Photo: ©FAO/Noel Celis

C 17. Wetlands in the eastern Free State, South Africa

Main characteristics: Failure, type 1.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
1	-+	+	-+	-

Wetlands in the eastern Free State of South Africa are a natural resource that provides various services predominantly for agriculture (both crop production and grazing) but also for other services that improve the well-being of the community. Yet, despite these valuable functions, many wetlands have been degraded. Belle *et al.* (2017) collected primary (field observations of wetlands, a survey among water users, and interviews with experts) and secondary data (climate parameters) to analyze the vulnerability of the wetlands for climate change effects. They found that a lack of a deeper understanding of wetland values and functions are an important cause for their deterioration. They also found that the wetland degradation is still on-going. The main recommendation was a proposed NBS intervention that is based on an integrated water management that should create a resilient environment for wetlands to absorb shocks caused by extreme weather events that are expected under future climate change conditions (excerpt from Belle *et al.*, 2017).

C 18. Rewarding water-related ecosystem services in the Cañete Basin, Peru

Main characteristics: Success, type 2.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	+	+	++	++

The main sources of surface water in the central and upper reaches of the Cañete watershed in Peru are precipitation, melting of glaciers or snow caps, small natural lakes, and springs. These sources are located in the upper watershed that hosts various ecosystems such as: high Andean scrublands, Andean wetlands, relict Andean forests, and some brushwood. The highest demand for water resources in this basin is concentrated in the lower watershed. The functioning of the ecosystems in the higher Cañete watershed provides two principal hydro-environmental services (HES): water yield and all-year availability of water, generating benefits for various sectors. Yet, upstream areas suffer from soil compactions due to increasing pressure from cattle grazing that results in declining water retention and an increase in runoff and soil erosion. The situation is exacerbated by the fast deglaciation process in the high Andean mountains due to climate change. In 2010, the Peruvian Ministry for the Environment (MINAM for its acronym in Spanish), with a set of partners, jointly initiated a project to evaluate and design a payment reward PES scheme in the Cañete River watershed (FAO, 2013a). The PES scheme targeted an investment in the HES. The initiative identified via hydrological modeling water uses and identified options to enable local communities to improve their livelihoods while conserving the area. The rehabilitation of degraded native pastures was done through improved forage management practices; the better management of disturbed wetlands ensure functioning and regulation of stream flows; the maintenance of well-conserved native grasslands, wetlands, and Andean forests will be guaranteed; and some sustainable businesses will be sustained to farmers as a way of recompensation for the conservation of the upper watershed ecosystem (excerpts from FAO, 2013a). Based on this experience, MINAM expects to develop 16 other similar PES initiatives in the country.

FIGURE 17
A farm in Peru's Cañete basin

Photo: CIAT

In parallel MINAM drafted a law proposal to promote PES mechanisms. The proposal recognizes the legitimacy of these mechanisms and encourages its use by local and regional authorities, civil society, and non-governmental organizations. The proposed law also mentions the possibility of public entities (e.g. local governments, public water supply companies) to invest and participate in PES schemes.

C 19. Ensuring groundwater recharge in a sensitive Michigan, USA watershed through PES

Main characteristics: Successful, type 2.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	++	++	++

The Paw Paw River Watershed has suffered from a 50 percent loss of wetlands since the 1800s and a decline of the functions once provided (excerpts from FAO, 2013). The most salient problems are surface runoff with excessive loads of sediment and nutrients from agricultural lands and overdrawing of the aquifer for irrigation. Traditional conservation programs presented by the United States Department of Agriculture (USDA) through the United States Farm Bill experienced challenges in this region due to slow adoption rates, low reimbursement payments, long waits for reimbursement and rigid rules, regulations and paperwork requirements (FAO, 2013b).

The Nature Conservancy (TNC) partnered with the local agricultural conservation agency in Van Buren County, Michigan to link with farmers in priority locations to encourage implementation of buffer strips and reduced tillage and no-till practices. In 2012, Coca-Cola enabled this initiative to test a PES scheme to incentivize farmers, providing farmers with a per-gallon incentive payment for the quantity of groundwater recharge increase that resulted from the implementation of conservation practices such as buffer strips, reduced tillage practices, and no-till. These new practices jointly added up to 100 million gallons (378.5 million liters) of increased groundwater recharge to the Paw Paw River over a three-year period (FAO, 2013b). In the initial years of the project, TNC scientists worked with Michigan State University to identify the key areas of farmland where agricultural best management practices would provide the most benefit to groundwater recharge.

C 20. Financial sustainability for environmental services: rural development in micro-watersheds, Rio Rural, Brazil

Main characteristics: Success, type 2.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	++	++	++	++

Between the years 2006-2011, the Global Environment Facility (GEF) in partnership with the Rio de Janeiro (RJ) Government provided a US$14 million grant to implement the RJ Integrated Agroecosystem Management project in productive landscapes of North-Northwestern Region of RJ State. The pilot project covered 48 micro-watersheds that supported 4000 small householders (FAO, 2013c). This area suffers from high rates of rural poverty, land degradation, and deforestation because of unsustainable land use and low productivity of the agricultural systems. This situation has – in large part- resulted from policies that have been historically in favor of mono-cropping of coffee and sugar cane and extensive cattle-raising, using deforestation and unsustainable production systems that caused soil depletion and degradation of water resources (FAO, 2013c). The project aimed to improve rural livelihoods and income through the adoption of sustainable natural resources management and conservation practices integrated into agricultural and non-agricultural systems. Increased productivity and increased biodiversity increases farmer resilience, reverses land degradation and allows for climate change adaptation and mitigation. The project managed (i) to increase awareness among small farmers, local managers, technicians and stakeholders about global environmental issues and their contribution to biodiversity conservation, water protection and climate change mitigation and (ii) to provide long-term support to small farmers in their transition to eco-friendly productive systems (excerpts from FAO, 2013c). As the project advances, a multi-stakeholder dialogue meeting, which took place in Rome, Italy mentioned that farmers are gradually adopting practices such as reforestation, spring protection, recovery of riparian vegetation, and protection of water recharge areas, sanitation, and road rehabilitation, green and organic manure, among other actions with direct impact on natural resources (FAO, 2013c). The pilot project is considered a Type 2 NBS intervention as it has the combination of green and grey infrastructure.

FIGURE 18
Farmers working the land with sustainable practices.

Photo: ©FAO/Alberto Conti

C 21. Engaging local business in PES. Lessons from Lake Naivasha, Kenya

Main characteristics: Success/Failure, type 1.

NBS typology	Trans- disciplinarity	Rewarding custodians	Institutional collaboration	Success/failure
2	+	+	+	-+

The PES project in Lake Naivasha, Kenya contributes to the enhancement of water quality, the reduction of on-farm soil erosion, the reverse of forest loss, and the improvement of livelihoods through various forms of compensation and an increase in agricultural productivity through the adoption of sustainable agricultural practices. The main incentive for farmers to join this initiative is the yield increase rather than the annual PES incentive. Two critical sub-basins were chosen as pilot sites: Upper Turasha (639 hectares) and Wanjohi (4680 hectares), based on the hydrological impact on the lake, the magnitude of sediment loads, population size and socioeconomic characteristics that influence the small-scale farmers' capacity to sustainably manage their lands (FAO, 2013d). The buyers of the environmental service were the water users downstream comprised of water companies, horticultural growers, ranchers and hotel/tourism industry. These companies remunerated farmers upstream for the measures adopted to improve soil and water conservation and thus for contributing to the improvement of the quality and quantity of water in the region. In 2012, 785 farmer households in the upper catchment became sellers of environmental services in the area making up roughly 4 percent of the total number of farm households in the upper catchment PES sites (excerpts from FAO, 2013d). The following measures to improve soil and water conservation on their farm were implemented: grass strips to check soil erosion and act as filter materials; agroforestry along the grass strips to reinforce the grass strips and improve the effectiveness in erosion control; river bank/riparian rehabilitation by planting grass and trees along the riparian areas to act as a buffer; good land management practices such as cultivating along the contours as opposed to across the contours.

Furthermore, the involved farmers are members of the local Water Resource Users Association (WRUA), which represents them as sellers within this scheme.

However, the project was difficult to upscale due to limited resources from the facilitating organizations as well as limited incentives from buyers to reach out to many farmers. The low buy-in of the buyers downstream is mainly because the watershed service is yet to be seen and upstream farmers and downstream buyers are working in trust and anticipation of the availability of the adequate clean water services in future (FAO, 2013d).

FIGURE 19
Map of the PES pilot sites within the L. Naivasha basin

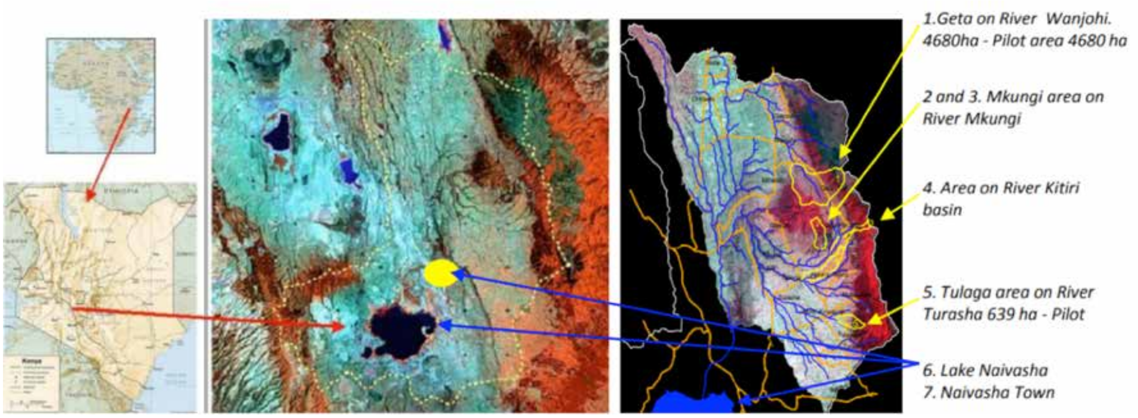


TABLE 2
Inventory of case studies

Name	Country	Ecosystem	Initiator/ funding	Stakeholders	Beneficiaries	Degradation process	NBS	NBS typology	Trans-disciplinarity	Rewarding custodians	Institutional collaboration	Success/ failure
C 1. Baviaanskloof /Tsitsikamma and uMngeni catchments	South Africa	Watershed	Development Bank, NGO's Governmental national/local	Municipalities, NGO's, provincial government researchers, farmers	Urban water consumers	Overgrazing	Restoring thicket	1	+-	--	--	+
C 2. Izta-Popo	Mexico	Land	Private company	Private company/urban population/land users	Private company/ urban population	Illegal logging, livestock grazing, fires	Reforestation/ infrastructure (pits and banks	2/3	+	+	--	++
C 3. Saye River bank failure	Nigeria	River	State	Communities/ farmers	Communities/ farmers	River bank erosion	Civil engineering structures	3	-	-	-	-
C 4. Athi River Kaiti,/Muuoni and Kikuu rivers	Kenya	Watershed	NGO's and local communities	NGO's and local communities	Local communities	Water scarcity and drought	Water harvesting technique (sand bars)/ agroecology	2	+	--	--	+
C 5. Water fund for catchment management	Ecuador	Watershed	NGO's, private companies, state	NGO's, private companies, state, farmers	Urban population/	--	++	1/2	+-	+	++	++
C 6. Ruvu watershed	Tanzania	Watershed	NGO's	Upstream communities, private companies industry, urban /rural population	Local communities companies, urban population and industry	River sedimentation	Restoration of rivers through the adoption of agro-ecological practices.	2	++	--	-	++
C 7. Lempa River	El Salvador	Watershed	FAO and GEF	Local communities and government staff in selected municipalities	Local communities and selected officials in the municipality	Soil degradation	Integrated natural resources management/ rainwater collection	2	++	-	++	++
C 8. Qanat Irrigated Agricultural	Iran	Watershed	Local communities	Local communities	Farmers and communities	Water salinization	Building natural irrigation systems	2	+	-	+	++

C 9. Horticulture production in the Kagera Basin	Burundi	Watershed	Local communities	Local communities	Farmers and local communities	Water scarcity and drought	Horticulture production systems	2	++	-	+	++
C 10. Shizuoka and Izu regions	Japan	Land	Local communities	Wasabi farmers	Wasabi farmers and communities	Water quality	Water quality management systems	1	+	+	+	++
C 11. Udayapur District	Nepal	Land	NGO and local municipality	Local farmers especially women	Women farmers	Soil degradation and drought	Compost pits	2	++	++	++	++
C 12. Improving water efficiency in the irrigated drylands of Egypt	Egypt	Watershed	Government	NGO’s, government and farmers	Farmers	Extreme Drought	Raised-bedding system	2	--	-	++	+
C 13. Groundwater management in Aweil East	South Sudan	Groundwater/ land	NGO’s/UN	NGO’s/UN/local government	Rural population/ farmers	Desertification	Pumping	1	-	-	-	-
C 14. Cauca Valley	Colombia	Watershed	NGO and associations	NGO, farmers, associations and private sector	Farmers	Sedimentation	Fencing, silvo-pastoral systems, reforestation	2	++	++	+	++
C 15. Lima’s surrounding watersheds	Peru	Watershed	Government and NGO	NGO, water utility authority, urban dwellers, peri-urban farmers	Urban dwellers and farmers	Water scarcity	Reforestation, pastoral reforms, wetland (amunas) restoration,	2/3	++	++	++	+
C 16. Forest Watershed Management	The Philippines	Watershed	Government at various levels	Local authorities and national government	Urban dwellers, farmers upstream	Degraded watershed	Reforestation, cooperation, new sources of livelihood.	2	++	++	++	+
C 17. Wetlands in Eastern Free State	South Africa	Wetlands	Communities	Communities/ Farmers	Communities/ farmers	Wetland degradation	Restoration programmes	1	-+	+	-+	+
C 18. Rewarding water-related ecosystem services in the Cañete Basin	Peru	Cañete watershed	Government, Private sector, local communities	Government, Private sector, farmers and local communities	Urban population and Farmers	Degraded wetland and miss management in the watershed	Conservation techniques-agroecosystem	2	+	+	++	++

Name	Country	Ecosystem	Initiator/ funding	Stakeholders	Beneficiaries	Degradation process	NBS	NBS typology	Trans-disciplinarity	Rewarding custodians	Institutional collaboration	Success/ failure
C 19. Groundwater recharge in a sensitive Michigan watershed	U.S	Paw Paw River-watershed	Government, Private sector, local communities	Government, Private sector, farmers and local communities	Government, Private company (Coca-cola), and farmer	surface runoff with excessive loads of sediment and nutrients from agricultural lands	Conservation techniques	2	++	++	++	++
C 20. Rural development in micro-watersheds	Brazil	48 Micro-watersheds	Small farmer-government – donor – world bank		Watershed degraded and land degradation	Reforestation	Agroecosystem Land management Reforestation spring protection protection of water recharge areas	2	++	++	++	++
C 21. Engaging local business in PES. Lessons from Lake Naivasha, Kenya.	Kenya	Lake Naivasha	International donor International institute (WWF and CARE)- private sector - Farmers - Service buyers : Flower companies, Hoteliers, Ranchers, Water supply providers	Farmers upstream and downstream.	Degraded public lands that influence the water quality	Water management practices	Farmers upstream adopted measures to improve soil and water conservation. Contributing to improvement of water quality and quantity	2	+	+	+	-+

4.2 SYNTHESIS

As we discussed in section 4.1 this paper does not claim to have a representative set of NBS interventions. An analysis is provided to identify potential indicators for successful NBS interventions and failed experiences in relation to the ecosystem, NBS-typology, stakeholder involvement, financial mechanisms, transdisciplinarity, and institutional collaboration.

Success/failure

The four failures found in our inventory were attributed to a lack of understanding of the functioning of ecosystems and ecosystem services [C 3, C 13, C 17, C 21). This was sometimes combined with a top-down planning without involving local communities (C 17) and involved armed conflicts that hindered the empowerment of people to take matters in their own hands (C 13).

Ecosystem

All case studies, except C 2, C 10, and C 11 refer to NBS that are part of a watershed ecosystem that is characterized by well-defined hydrological boundaries and interconnecting water flows that cannot be partitioned without affecting other users. It confirms our argument forwarded in sections 2 and 3 on the need for collective action when NBS interventions are planned.

NBS typology

Of the evaluated case studies five (C 1, C 5, C 10, C 13, C 17) are associated to NBS typology 1, sixteen (C 2, C 4, C 5, C 6, C 7, C 8, C 9, C 11, C 12, C 14, C 15, C 16, C 18, C 19, C 20, C 21) qualify for a type 2 label and three (C 2, C 3, C 15) as type 3. One case study (C 5) is categorized as hybrids of types 1 and 2 and two (C 2, C 15) of types 2 and 3. We can cautiously conclude that NBS interventions are diverse and cover the full range of typologies and their hybrids. Different experiences show a wide array of results.

Stakeholder involvement

As interventions at watershed level impact downstream users, a basin-wide stakeholder involvement is prerequisite for successful implementation of NBS as confirmed by case studies C 1, C 2, C 5, C 6, C 7, C 8, C 9, C 10, C 11, C 14, C 18, C 19 and C 20 that have the highest success rates. Interesting examples illustrate that stakeholder involvement can be organized in various ways. Case study C 2 uses stakeholder buy-in which became the key to the economic success of the NBS project. Case study C1 made a compelling call to seek wide support among national and local governments, researchers and local water users for the large-scale protection and rehabilitation of ecological infrastructure that should increase water quantity in catchments. In contrast, case studies C 3 and C 13 elucidate that top-down approaches that lack any involvement of local communities, all failed to meet at least part of their objectives. Though some cases (C 17) did not consider ecological impacts at the inception stage, other examples that are more recent confirm that multi-stakeholder involvement is still not always guaranteed as part and parcel of NBS. The absence of an organizational structure, the disruptive effect of armed conflict on social cohesion, and possibilities to organize people become most visible in the case of studies C 17 and C 13, respectively. Case study C 6 shows an interesting example of public-private collaboration in promoting a PES scheme, implemented in the period 2006-2011, between downstream customers (industry, local sewerage services, and a beverage company) and upstream suppliers (farmers).

Financial mechanisms

Creating and organizing funds fosters a sustainable and lasting positive impact of NBS on the environment and on the end users of water. Case studies C 5, C 14, C 15 and C 18 shows that the establishment of operational funds contributed to successful or very successful NBS interventions. We observed that these funds operate at a watershed level and were supported by multiple contributors organizing a broad support for NBS interventions. A special highlight in this respect is the Ecuadorian case (C 5) that established a water trust fund to provide financing of watershed conservation activities. Although it took seven years before the fund became operational, it was supported by private and public institutions and involved all water users. An interesting operational PES scheme is presented in C 6 where farmers received payments to incentivize the adoption of good practices to reduce soil erosion and improve the water quality of downstream users.

Transdisciplinarity

In our assessment, the use of local knowledge is positively related to the success rate of NBS. Very high scores for case studies C 6, C 7, C 9, C 11, C 14, C 19 and C 20 corresponded with very high success rates. Very high scores for C 15, C 16 and C 20 correlated with high success rates. Interesting and informative are the cases studies where centuries-old indigenous knowledge led to finding lasting solutions for water delivery in, for example, an arid regime where ingenious underground water system assured the timely delivery of fresh water (C 8) while traditional upstream soil and land use management systems conserved water flows from becoming erosive (C 10).

Institutional collaboration

Strong ties between institutions involved in the NBS are fundamental for organizing stakeholder involvement and coordinating NBS implementation that often takes place at a level higher than the individual one. Case studies C 5, C7, C 9, C 11, C 18, C 19, C 20 and cases C 12, C 15 and C 16 show that well-organized collaboration between institutions has a very successful and successful rating, respectively. The absence of institutional collaboration can lead to failure (C 3, C 13) unless it is compensated by a high level of transdisciplinarity (C 4, C 6) sometimes combined with a well-functioning rewarding scheme (C 2).

We conclude that many of the findings from the case studies confirm our analytical results of sections 2 and 3. Transdisciplinarity, stakeholder involvement, and well-organized funding schemes are important elements for successful implementation of NBS. Furthermore, the endurance of the NBS is required to organize participatory and transdisciplinary platforms, implementation of payment schemes and restoration of activities that usually cover large areas. Surprisingly, in our NBS case studies the valuation of natural resources and ecosystem services is solved by imposing payment schemes that were reached after joint agreements of stakeholders or the decision-making process were based on other criteria. In both cases, a tedious exercise of natural resource valuation was omitted.

Photo: Pexels

5. Conclusions

In the previous section, this FAO discussion paper analyzed case studies where NBS was implemented in the agricultural water management context. Main findings concluded that NBS failed interventions were attributed to a lack of understanding of the functioning of ecosystems and ecosystem services as well as a combination of a non-participatory and top-down approach. In addition, NBS interventions were wide and varied. Each intervention has its particularity in regards to geographic location, political context, and community involvement. In most NBS success stories, communities were involved from the beginning of the NBS intervention, which gave them a sense of ownership. The absence of an organizational structure, the disruptive effect of armed conflict on social cohesion, and opportunities for people to get organized were evident in failed case studies. Finally, case studies demonstrated that NBS requires an initial investment, which may deter communities to implement it. However, in the long-run benefits outweigh costs.

Conceptually NBS covers a wide spectrum of activities and concepts. More specifically it includes "All 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" (Cohen-Shacham *et al*., 2016). Furthermore, the United Nations World Water Development Report of 2018 concludes that NBS is a flexible concept that covers a wide range of techniques and policies that vary in the degree of intervention in the functioning of ecosystems.

What matters here is that the bipartite objective of NBS in water management interventions is focused on how best to serve the well-being of humanity while minimizing their impacts on the functioning of ecosystems. The accommodating character of NBS might result in multiple, yet, conflicting interests, and trade-offs of interventions should be discussed among the various stakeholders.

NBS is no longer a theoretical structure, rather it is widely used as a practical set of interventions, actions, and rules that are efficient and economically feasible. Some of the case studies show that NBS interventions that combine green with grey infrastructure are more efficient than grey infrastructure alone. However, it was also found that investments in NBS water management and related green infrastructure are only a small fraction of the required investments to sustain and protect the prevailing ecosystems. Therefore the key question is seen to be: Why is it so difficult to implement NBS measures? And what are the pre-conditions to create an enabling environment for NBS?

The answer is rooted in the intrinsic dependence of NBS on the functionalities of ecosystems, which creates two problems. First, it is difficult to set prices for these ecosystems services and amenities that could comprehensively quantify the value of these complex ecosystems in a complete and precise manner. This makes it difficult to quantify and compare the benefits of NBS on the balance of positive and negative rewards of grey infrastructure. A further additional complication is that the time span for valuation of NBS interventions in a cost-benefit analysis takes long periods of time that increases the uncertainty imposed by the choice of the parameters, in particular, the discount rate. Additionally, pricing becomes less meaningful when critical ecological thresholds are being approached and ecosystem services become non-substitutable (Greenhalgh *et al*., 2017). The complexity of pricing eco-system services might also explain why the detailed and tedious practice of natural resource valuation was largely absent in our case studies. There is no escape option here. Work is needed on improving the valuation methods and dealing with the uncertainties inherent in the system.

Second, the ecosystems considered are usually large and lumpy and contingent on interconnecting biophysical flows and migrating organisms that cannot be partitioned into smaller units without affecting other sites. The first issue about lumpiness can, in principle, be solved by adequate eco-system valuation that is recommended above. Yet, even if taxation and user fees for ecosystem use could be based on proper prices, experience teaches us that this is not sufficient to prevent degradation, because agreements on monitoring negative externalities or rewarding the efforts of custodians are difficult to monitor and implement. The much-promoted solution to assign property rights to parts of the ecosystem need not be a viable pathway either, precisely because of the second issue that ecosystems only function well in its entirety; assignment of individual property rights could destroy the essential productive properties of the ecosystem that only work as a whole. Our case studies indeed show that the indivisibility issue of ecosystem services may be successfully addressed by collective action that reconciles the conflicting interests of all stakeholders involved in a transdisciplinary approach.

It follows from the above discussion that a decision framework is required which explicitly takes into consideration the trade-offs between the benefits of NBS interventions and the impact on ecosystems when alternative options are compared. A long-term sustainable perspective of this decision framework should also guarantee the preservation of ecosystem services for future generations.

A ROAD MAP FOR NBS INTERVENTIONS; INTER- AND TRANSDISCIPLINARY APPROACH

The aim of a road map for NBS interventions is to create a productive stakeholder engagement that balances the interests of resource users against the quality and sustainability of the ecosystem. This social process starts with a structured inventory of actors (individuals, groups and organizations) involved and their interests, acknowledging that each actor has its own goals and strategies and that there are, as in any political process, possible conflicting objectives among participants. Indeed, for participants, NBS interventions can be ambitious. They are also highly complex in nature and potentially impact many existing development policies. Hence, the tendency to seek solutions in a mono-disciplinary manner in isolation should be avoided as this simplifies reality and omits the prevalent key characteristics of the impact of NBS on the ecosystem.

In this full and comprehensive involvement process, the lack of shared understanding looms large and might result in polarization and erosion of mutual trust. NBS interventions should, therefore, be designed to be both inclusive of, as opposed to competitive with, other ecosystem management strategies and related urban and rural planning activities. Structural stakeholder engagement strategy, therefore, involves an active participation and co-design of NBS management plans. This joint stakeholder process benefits immensely from the development of dedicated support tools. These tools could provide adequate representation of the spatial and temporal dimensions of ecosystems and their relation to specific ecosystem services. The developed tools may include illustrating results of NBS interventions in synoptic tables and colorful maps that are interpretable for a large audience and makes comparisons between various options possible. Effects of NBS on ecosystem services that are related to water availability for agriculture, human consumption and industrial use can be quantified in monetary terms; the impact on ecosystem services like biodiversity, that are less quantifiable, can be represented by changing eco-indicators and proximity of the ecosystem quality to critical thresholds.

Concerning the practical development of these support tools, they typically combine theory and accumulated experience to represent the complexity of the ecosystem. When constructing such models several considerations should be taken into account. To start with, the model should be able to accommodate data of various formats from different sources and harmonize the information into an analytical framework that can be used for evaluation. Modern data architecture can capitalize on the many georeferenced surveys that are available and link household information to spatially-distributed biophysical attributes (land use, soils, climate, and topography). In the absence of these georeferenced socio-economic information sources, the model should calculate measurable aggregates that are mostly of an economic nature, against which the predictive performance of the models is tested. For spatially distributed water flow models, consistent aggregation protocols are available (Keyzer, 2015) that ensure an accurate representation at the aggregated level of inflows and outflows at the finest resolution, avoiding double-counting. Furthermore, many of these support tools are of a modular nature that facilitates the organization of work among the various disciplines involved. It is to be noted, however, that a modular structure does not often comply with the standard assumptions of economic theory and, hence, cannot be placed in an optimization framework. Comparative statics can be used instead without much loss of generality. Estimation and calibration remain, in this case, by-and-large eclectic as rigorous processes are lacking and it is difficult to estimate the model in full. Hence, as an informal sequence of estimations causes equi-finality, the same result is being reached by different sets of parameters and the model becomes prohibitive for policy purposes. Therefore, it is preferable to create models with an overarching mathematical structure that maintains the fundamental constraints on dynamics (Doherty, 2016). As such, the development of tools can be helpful in this process by creating an enabling environment and a broad acceptance of NBS.

BOX 5

A roadmap for NBS interventions

The five-step roadmap for NBS interventions (Figure 2), as presented in the discussion paper, should create a productive stakeholder engagement that balances interests of resource users against quality and sustainability of the ecosystem.

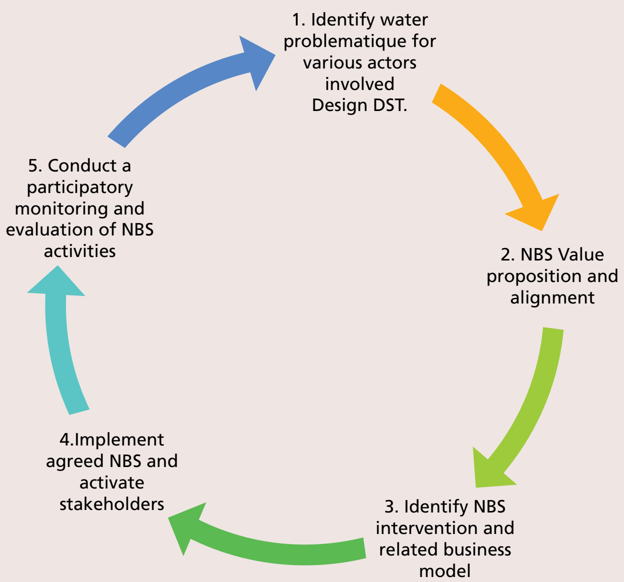
Step 1. This social process starts with a structured inventory of the problematic, actors involved and their interests, acknowledging that each actor has its own goals and strategies.

Step 2. In a process of alignment the project seeks to solve possible conflicting objectives and acknowledges retention of the subsidiarity principle: assuring active involvement of stakeholders that are closest to where NBS has its main environmental impact. This joint stakeholder process benefits immensely from the development of dedicated support tools (DST) that accumulate the multi- and transdisciplinary know-how and provide an adequate spatially and temporal representation of the impact of NBS interventions on ecosystems.

Step 3. A business model should describe how NBS adds value to its users and how it is financed.

Step 4. The implementation follows a management plan where the project is decomposed in smaller components that are formulated in terms of work packages and deliverables.

Step 5. A monitoring scheme provides a comprehensive analysis of the monetary and ecological costs and benefits to adequately informed stakeholders. Moreover, the monitoring scheme is used to reward the good functioning of NBS and to penalize abusive interventions.



Summarizing, the joint stakeholder initiative should comply with the following elements:

- Identification of stakeholders;
- Jointly designing and managing a stakeholder platform together with stakeholders for continuous monitoring and feedback on developments with enabling meaningful inclusion of the most marginalized through targeted, individual capacity enhancements;
- Design of schemes that reward good functioning of NBS and penalizes abusive interventions;
- Comprehensive analysis of the monetary and ecological costs and benefits to adequately inform stakeholders and assist the decision-making process;
- Implementation of conflict resolution mechanisms;
- Retention of the subsidiarity principle: assuring the active involvement of stakeholders that are closest to where NBS has its main environmental impact; and
- Implementation of a monitoring scheme for evaluation of NBS interventions that provides feedback to stakeholders.
- Incorporating a system-wide, country-driven capacity enhancement approach[11] that interdependently empowers people, strengthens organizations, institutions, multi-stakeholder processes and sharpens the enabling policy environment based on assessed needs for more sustainable NBS interventions at scale

As confirmed by the case studies, this road map asks for lengthy periods of time to organize the participatory and transdisciplinary platforms, the monitoring and evaluation of schemes and funding as well as execution of the NBS intervention, which makes this process costly and requires endurance of its promoters. Yet, the hope is that the lasting positive effects of well-designed NBS interventions will outweigh the inconsiderate quick wins that are largely based on ignorance.

[11] See for instance FAO. 2017. Enhancing Capacities for Country-Owned Transition Towards Climate Smart Agriculture. Climate Smart Agriculture Sourcebook.

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12
LAND AND WATER DISCUSSION PAPER

Nature-Based Solutions for agricultural water management and food security

Accessibility to clean and sufficient water resources for agriculture is key in feeding the steadily increasing world population in a sustainable manner. Nature-Based Solutions (NBS) offer a promising contribution to enhance availability and quality of water for productive purposes and human consumption, while simultaneously striving to preserve the integrity and intrinsic value of the ecosystems. Implementing successful NBS for water management, however, is not an easy task since many ecosystems are already severely degraded, and exploited beyond their regenerative capacity. Furthermore, ecosystems are large and complex and the many stakeholders involved might have conflicting interests.

Hence, implementation of NBS requires a structured and comprehensive approach that starts with the valuation of the services provided by the ecosystem. The whole set of use and non-use values, in monetary terms, provides a factual basis to guide the implementation of NBS, which ideally is done according to transdisciplinary principles, i.e. complemented with scientific and case-specific knowledge of the eco-system in an adaptive decision-making process that involves the relevant stakeholders.

This discussion paper evaluated twenty-one NBS case studies using a non-representative sample, to learn from successful and failed experiences and to identify possible causalities among factors that characterize the implementation of NBS. The case studies give a minor role to valuation of ecosystem services, an area for which the literature is still developing guidance. Less successful water management projects tend to suffer from inadequate factual and scientific basis and uncoordinated or insufficient stakeholder involvement and lack of long term planning. Successful case studies point to satisfactory understanding of the functioning of ecosystems and importance of multi-stakeholder platforms, well-identified funding schemes, realistic monitoring and evaluation systems and endurance of its promoters.

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