Using Spatial Information to Remove Barriers and Foster Enablers: The Uptake of Nature-based Solutions for Food Production and Water Resource Management in Ghana and the Netherlands

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Abstract

Water-related problems caused by climate change threaten the future of food systems in both the Netherlands and Ghana. In this paper, we present the results of a comparative case study analysis. The objective is to identify similarities in the use of spatial information by experts and stakeholders in their attempts to remove barriers or foster the enablers of the uptake of Nature-based Solutions (NbS) in view of climate change. Experiences in this field have been assessed, by using the Food System Approach (FSA), in the Rhine-Scheldt Estuaries (the Netherlands) and the Bono East Region (Ghana) in relation to rainwater harvesting (RWH) and the reuse of wastewater, which are considered as hybrid nature-based solutions. Both rainwater harvesting and wastewater treatment techniques are available, and ready to be accepted and applied by farmers and the food processing industry. Their uptake, however, is hampered by multiple barriers, ranging from biophysical and technical barriers to social and institutional barriers. We conclude that spatial information can be an enabler for the adoption of nature-based solutions if that information is applicable for the assessment of a wide range of possible solutions for water scarcity in the frame of food production – either nature-based solutions or technologies. In both case studies, we observe a struggle to make the future spatially explicit due to the availability of spatial information of all relevant factors. The involvement of stakeholders in the process of creating spatially explicit information for the suitability of NbS was valuable in both case studies, in terms of identifying driving factors, and improving the adequacy of the suitability maps.

Keywords: *climate, water, food, nature, nature-based solution, climate adaptation*

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1. Introduction

In this paper, we present the results of a comparative case study analysis. The objective is to identify similarities in the use of spatial information by experts and stakeholders in their attempts to remove the barriers, or foster the enablers of the uptake of Nature-Based Solutions (NbS). NbS use and deploy the properties of natural ecosystems and the services that they provide in a smart and in some cases an "engineered" way. The uptake, or upscaling of NbS, is often hampered by multiple barriers, ranging from biophysical and technical barriers to social and institutional barriers. The uptake or adoption of NbS differs from the adoption of technology as NbS will be spatially specific, as the basic design principle is based on the properties of natural ecosystems. In addition, some scholars in water management (Janssen et al., 2019; Smit et al., 2014) state that stakeholders may argue that NbS must become evidence-based before they can replace conventional ways of water management strategies (the innovation dilemma). In this study, we focus on the role of NbS in agriculture and water management. The paper also considers that enablers and barriers can also occur elsewhere in the food chain.

Experiences in this field have been assessed in the Rhine-Scheldt Estuaries (the Netherlands) and the Bono East Region (Ghana) about the reuse of wastewater and rainwater harvesting. The analysis focuses on identifying similarities in the use of spatial information by stakeholders in their attempts to remove the barriers or foster the enablers of NbS uptake. The paper evaluates the essential requirements in developing spatially explicit scenarios for NbS in view of climate change, in a participatory setting. The lessons learnt in both countries provide guidance for embedding NBS in their socio-spatial and biophysical context.

First, we describe the water-related problems that are encountered in relation to climate change, for which rainwater harvesting and water reuse may provide a nature-based solution. Secondly, we present recent research on the adoption of NbS, and the challenges which are generally encountered regarding their uptake. Thirdly, we focus on barriers and enablers that are relevant for both case studies and where the availability of spatially explicit information may play a role in the decision to adopt NbS, considering the differences of the different food systems.

Food security and climate proof water supply

The world's population is predicted to rise to 9.7 billion by 2050 (United Nations, 2019). This prospect puts a strain on the global food security and water supply. In future, more water will be needed to produce enough food for a growing world population, but also for the maintenance of water resources, and the maintenance of those economic activities that rely on the available water resources. The availability of freshwater resources for food production is at risk due to climate change and the increasing water demand by multiple users in many parts of the world (IPCC, 2014, 2018, 2021; Shukla et al., 2019; World Water Council, 2000). Reduced and erratic rainfall, reduced streamflow and groundwater recharge, coupled with increased domestic, industrial, and crop water demand pose major climate-related risks to agriculture, water utilities, and hydropower production (Immerzeel et al., 2020). FAO estimates that at least 25% of the costs of damage and loss from climate-related disasters are absorbed by agricultural sectors (FAO, 2015).

Policymakers, scientists, and social actors are therefore working on strategies to ensure food security and water supply in the long-term. Not only for securing a long term food security, but also to reduce the risks to investors, and to maintain their interest in continuously investing in the production of food (Chiriac et al., 2020; Verdegaal et al., 2018). As risks rise, the discussion as to which sector is responsible for taking the risks rises as well (Mauelshagen et al., 2014), leading to a call for innovative public-private financial arrangements or otherwise blended finance. Across the globe, new pathways are explored to ensure that all people have access to affordable, sufficient, and nutritious food all year round, and to ensure the sustainable use of water resources to support this. There are also studies that explore how resilient these pathways are under different climate scenarios (Achterbosch et al., 2014; FAO, 2018; Haasnoot et al., 2020; Mens et al., 2022). In general, it can be stated that in delta areas and river catchments, water availability for food production comes under increasing pressure due to climate change, sea level rise, and related increased salt water intrusion (Thorslund et al., 2021). Especially in regions where the water supply is mainly dependent on rainwater (Iglesias & Garrote, 2015).

In many parts of the world, boosting local economic development is key to achieving food security and a better quality of life. To combat rural poverty, food security must increase in terms of quantity, but also in terms of food quality, income, and in terms of resilience to increasing weather extremes induced by climate change. Addressing these multiple goals simultaneously, however, requires more efficient use of natural resources such as water. The challenge herein is to increase the availability of water through temporal storage, or otherwise use less water while producing more food with less impact on biodiversity. To do so, there is a growing recognition for the need to change our current linear ways of producing food and feeds into circular systems by closing water, nutrient, and carbon cycles, and consequently minimising resource loss and mitigating climate change impacts.

Nature-based solutions

Increasing awareness that nature can be a source of inspiration in providing viable contributions to reduce the impact of anticipated negative effects of climate change (Sonneveld et al., 2018). These so-called 'nature-based solutions (NbS),' or interventions use and deploy the properties of natural ecosystems and the services that they provide. The term NbS is derived from environmental sciences, water engineering, and agricultural sciences. Its first appearance in mainstream scientific literature was in the early 2000s, amongst others in integrated pest management and the use of (constructed) wetlands for wastewater treatment (Potschin et al., 2016). In NbS, there are gradations in the use of natural processes, the level and type of engineering applied to ecosystems and the number of ecosystem services delivered (Cohen-Shacham et al., 2016; Eggermont et al., 2015; Somarakis et al., 2019). Also, in the field of water engineering, experience has been gained with NbS in the last decade. For example, in the Netherlands pilots, research projects and also real-life interventions along the coast have been initiated (Bouw et al., 2020; De Vriend et al., 2015; Slinger & Vreugdenhil, 2020; Willems et al., 2021).

Different definitions for NbS are in use, while in this paper we use the following definition from the EU Research and Innovation policy agenda as a starting point:

> *". . . measures that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits and help build resilience. Such solutions contribute to more biodiversity and other natural features and processes into cities, landscapes, and seascapes, through locally adapted, resource-efficient, and systemic interventions*."
> (European Commission, 2015).

With this definition of NbS, we can link the impact of NbS to biodiversity as well as the food system (Keesstra et al., 2023). We realise that opponents of this definition argue that its emphasis on cost-effectiveness may lead to NbS that prefer economic, rather than social and environmental outcomes. We do believe, however, that including the cost-effectiveness of NbS is appropriate, as it secures their sustainability towards nature-inclusive activities. Moreover, Keesstra et al. (2023) provided a typology of NbS: *i*) intrinsic NbS which make use of existing ecosystems; *ii*) hybrid NbS which manage and adapt ecosystems; and *iii*) inspired NbS which consist of newly constructed ecosystems. RWH and water reuse are examples of the hybrid NbS according to the typology of Keesstra et al. (2023).

NbS for food and water security – i.e., hybrid NbS – can be implemented on different scales (e.g., farm, watershed, landscape, and region) and require multi-level governance support. Examples at the farm level are mixed cultivation, biological pest control, agroforestry, water treatment, and harvesting. On the landscape level, nature-based interventions may be more complex and partly nested, responding to the multiple landscape functions and services provided at the landscape level. For example, nested NbS may address the reuse of production water and nutrient flows from the food processing industry, while at the same time constructed wetlands can be used to purify wastewater for irrigation in agricultural areas. NbS, on the landscape level, usually aim to make better use of natural dynamics in land, water, and sediment fluxes, and combine these with the socio-economic, political, and cultural dynamics at stake and different scales (Vreugdenhil et al., 2010).

Enablers and barriers for adoption of nature-based solutions

Enablers and barriers that determine the adoption of a new technology or policy strategy at the interface of the environment, climate, and food supply have been frequently researched (Abdallah et al., 2014; Bolson & Broad, 2013; Liu, 2013; Veraart et al., 2017). This also applies to the NbS that are central to this comparative case study analysis (Calliari et al., 2022). The success or failure of adopting a NbS or changing operational management at farm level will also depend on enablers and barriers elsewhere in the food chain and in water management. It seems evident that a food system approach could add value, as it facilitates assessing the multiple enablers and barriers that are relevant to different components of a specific food system (Alarcon et al., 2021; Ingram, 2011; van Berkum et al., 2018). In this study, the Food System Approach is used to select indicators (section 2).

Embedding NbS in agricultural practice, food processing, and water management in view of climate change will require *major changes* in their necessary skills. The change may require more than an adaptation in business operations or adaptive management (Terwisscha van Scheltinga & Timmerman, 2020). In order to embed NbS, the required change can also mean that the agricultural entrepreneur has to completely transform his or her production system, which requires completely different skills and technologies (Wojtynia et al., 2021). The question is sometimes raised whether this *change process* can be managed, often qualified as ‘transition management’ (Köhler et al., 2019; van der Brugge et al., 2020).

The role of spatial explicit data and information in adopting nature-based solutions

On all spatial scales, decisions are taken by public and private actors about the use of natural resources (water) and the adoption of NbS. Many barriers and enablers are caused by often unpredictable feedback stemming from decisions between these different scales. In addition, the actors involved may have an uncertainty-reducing behaviour in decision-making (enablers), while others continuously pose new questions and uncertainties (barriers) (Veraart et al., 2018). The availability of scenarios for solutions and climate change applicable on different spatial scales is also mentioned as a barrier in various studies (Kanellopoulos et al., 2014; Van den Hurk et al., 2013).

Spatial data and information play a vital role in adopting NbS. They are essential in identifying the potential locations, types, and configurations of NbS that can maximise their effectiveness and co-benefits, while minimising their costs and trade-offs (Mubeen et al., 2021; Sarabi et al., 2022). They are also essential in simulating the hydrological and ecological effects of NbS under different scenarios and conditions, such as climate change, land use change, human interventions, and uncertainty (Gómez Martín et al., 2021). In addition, spatial data are important in facilitating the participation and collaboration of different stakeholders and sectors in the design and management of NbS, such as water managers, policymakers, researchers, and practitioners (Verweij et al., 2016). Finally, spatial data allows for the quantification of the ecosystem services and human well-being benefits of NbS (Gómez Martín et al., 2021; Paulin et al., 2020). In general, spatial data and information are key enablers and drivers of NbS adoption, as they can provide valuable insight, evidence, and guidance for decision-making and planning processes. However, spatial information also faces some challenges and limitations, such as data availability, quality, and interoperability, as well as ethical, legal, and social issues.

Increasing the usability of spatial information about NbS for decision-making in water management and food systems is challenging because this has to be done simultaneously on different scales, each often with its own science-policy interface or disparate knowledge systems (O'Toole & Coffey, 2013).

The structure of the study is as follows. In Section 2, a methodological approach and the data collection are presented. Section 3 discusses two case studies on NbS, one in the Netherlands, and one in Ghana, which will be compared. In Section 4, the results of the comparison are discussed, and Section 5 presents our conclusions.

2. Our methodological approach and data collection

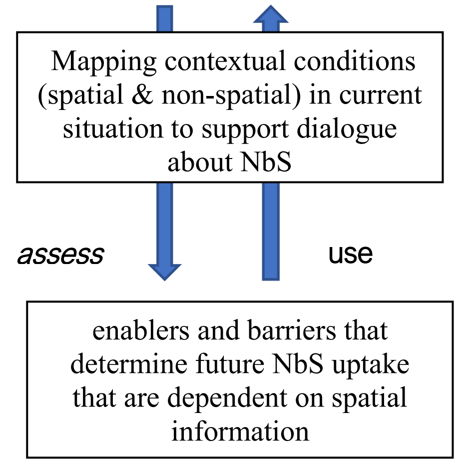
2.1 Approach

Case study analysis is an accepted qualitative research method to unravel complex knowledge systems where rationality, power, and intuition shape each other in decision-making (Flyvbjerg, 2006). The methodological design of this study builds upon a comparative case study approach (Yin, 2009).

The phenomenon of study is the role of spatial information in stakeholder processes that have the objective to assess the feasibility of adopting NbS, as exemplified by Rainwater Harvesting and Wastewater Reuse. This is done by identifying similarities in the use of spatial information by experts and stakeholders in their attempts to remove the barriers, or foster the enablers of the uptake of Nature-Based Solutions (NbS) in view of climate change.

First, the following contextual conditions are described for each case study (Chapter 3): (a) Water supply conditions, (b) Food supply conditions, (c) Environmental conditions, (d) Socio-economic Institutions, and (e) Available alternatives for NbS. The conditions and potential indicators were selected from, amongst others, the Food System Approach (Alarcon et al., 2021; van Berkum et al., 2018).

Table 1. *General set up of the comparative case study analysis.*

Contextual conditions	**Possible indicators**	**Ghana**	**Netherlands**
		current	*future*
Water supply (Spatial explicit)	Water Gap Risk (supply < demand) Adaptive capacity to climate change		
Food Supply	Food Gap Risk (Supply < Demand)		
Environment	Biodiversity Soil		
Socio-economic & institutional	Land tenure Policy incentives and support		
Alternatives for NbS (Rainwater Harvesting & Water reuse)	Available alternatives Added value NbS for Food System Income Effect for Farmer from NbS		

The choice for case studies in Netherlands and Ghana may seem a far stretch. However, there are reasons why the authors decided for these cases. Comparing case studies in both Ghana and the Netherlands is relevant because, despite different contextual conditions, both case study areas experience increased pressure on water resources, especially in relation to food production because of climate change. In addition, both case studies share the barrier of enablers for implementing NbS differently perceived by stakeholders on the landscape level and on a landowner's plot. The usability of spatial information in both case studies was compared to the aim of identifying the essential requirements that this information must meet to be relevant for decision-making on multiple levels (food system, landscape, farm). Figure 1 presents the enablers of both case studies using the dots at the bottom of Figure 1. In Ghana, farmers and the stakeholders involved in the landscape are the key enablers. In the Netherlands, farmers and wastewater collectors are the key enablers.

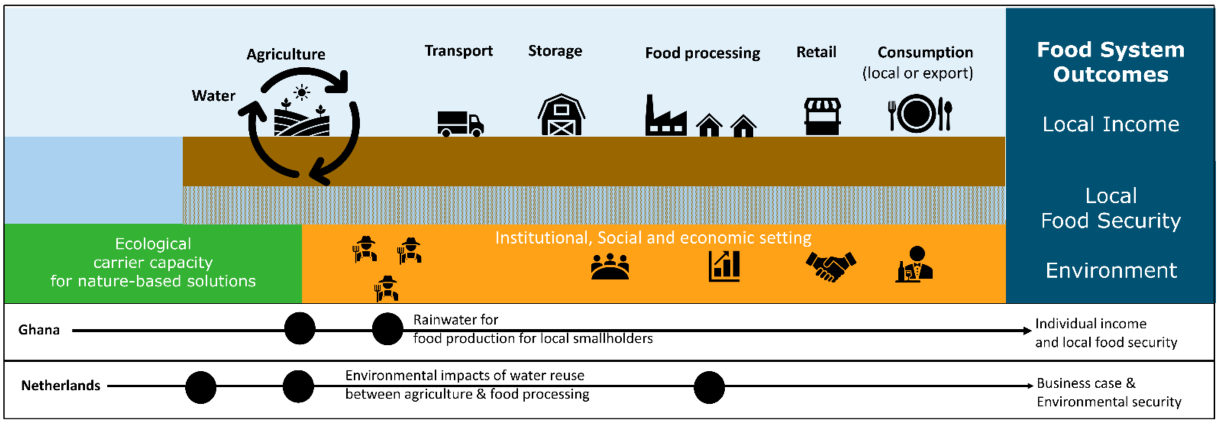


Figure 1. *The case studies (Ghana & the Netherlands) were framed in the perspective of the (Water &) Food System Approach. The black circles indicate by case study which part of the food system has been studied in this comparative case study.*

In addition, for more than four centuries, the food systems of the Netherlands and Ghana have been highly interrelated. Imports by the Netherlands from Ghana in 2021 amounted to more than 700 million USD, of which almost $600,000,000 reflect agricultural products (UN COMTRADE database on international trade, 2022).

2.2 Stakeholder participation in the Netherlands and Ghana

The case studies in the Netherlands and Ghana share a commonality that spatial information was used about the water supply and agricultural water demand to develop feasibility maps. However, the tailoring of spatial environmental data has been done in different ways (section 2.3 & 2.4), which is inherent to the chosen strategy to develop feasibility maps with local stakeholders from both countries. Also differences in the availability of spatial data in the case studies played a role. Feasibility maps concerned the reuse of wastewater in the Netherlands and rainwater harvesting in Ghana, respectively.

Stakeholders that contributed to this analysis in both case studies originated from the national science policy networks in which the authors are active, we are aware of the bias this can entail. Examples of those science-policy networks are, amongst others, the Dutch national Delta programme (Staf Deltacommissaris, 2019), the Dutch Knowledge, the Innovation programme "Agriculture – Water and Food"(KIA -LWV, 2022), Solidaridad West Africa (Solidaridad, 2022), and the Forestry Commission of Ghana. Table 3 gives an overview of the stakeholders who actively participated in workshops, field trips, or were interviewed.

The researchers in Ghana already had a coordinating role in arranging stakeholder meetings within the Forestry Commission of Ghana and Solidaridad West Africa before the start of the study. This allowed for stakeholder workshops to be embedded in ongoing activities. In the Dutch case study, a start was made with bringing together stakeholders who are active in either national science policy networks concerning water management or wastewater treatment technology. Different networks needed to be bridged. The research was implemented during the global COVID-19 pandemic, which made it hard to consult with stakeholders directly in both case studies.

In the Netherlands, the approach could be described as a stakeholder consultation, while in Ghana the process was more collaborative (Termeer et al., 2015; Wardenaar, 2015) . In the Netherlands, the stakeholder participation focused on improving feasibility maps for wastewater reuse with available national water, soil, and land use models. Like the Netherlands, in Ghana, stakeholder participation also focused on improved suitability maps of rainwater harvesting which had been initially produced solely because of literature reviews.

Table 2 illustrates that in Ghana mainly stakeholders from the agricultural sector were involved, while in the Netherlands the focus was on involving the food processing industry.

Table 2. *Overview of consulted stakeholders in the Netherlands and Ghana.*

The Netherlands	
Stakeholder	*Consultation method*
Drinking water supply factory (PWN, EVIDES)	Bilateral meetings (December 2021)
Food processing Factory (pre-fried fries)	Bilateral meeting (May & June 2021)
Food processing Factory (potatoes)	Workshop (December 2020)
Regional Water Authority (Scheldestromen)	Workshop (December 2020)
Province (Zeeland)	Workshop (December 2020)
Consultants & Experts	Workshop (December 2020)
Brewer (beer)	Interview
Ghana	
Stakeholder	*Consultation method*
Agricultural department (Techiman North District)	Three-day field trip meeting (December 2020)
Farmer associations	
Community leaders	
Farmers (n=34)	Interviews with farmers from Adutwie, Kyiridiagya, Ofuman, Bonya and Tanoboase (communities)
Department of Environmental Management	Three-day field trip meeting (December 2020)
Extension officers (n=5)	
Solidaridad West-Africa	Existing stakeholder network, co-researcher
Forestry Commission Ghana	Existing stakeholder network, co-researcher

Stakeholder participation in the Netherlands

The feasibility map for the Southwestern part of the Netherlands was developed, step by step, whereby the map was adapted in dialogue with policymakers and practitioners by means of a workshop, bilateral meetings, and interviews (Table 2). In this way, the assumptions beyond the map were also validated by stakeholders, and knowledge needs were identified. Subsequently, the workshop examined which combinations of NbS and water technologies could be used in the future to use this potential water source as climate adaptation in this part of the Netherlands. Based on the stakeholder consultations, enablers and barriers were identified for applying NbS as a measure to increase climate resilience of landscapes and food production chains by expert judgment.

Stakeholder participation in Ghana

In Ghana, the approach to developing suitability maps for rainwater harvesting was iterative and dynamic.

Initially, these maps were created based on a comprehensive literature review, without direct stakeholder engagement – but with the expertise of the research team. Subsequently, field work was conducted to check the accurateness of the maps which took place in the terrain in the Bono East Region. The field team visited the Techiman North District at the end of 2021, and they took georeferenced photos which were later integrated into the suitability map. During the field trip, interviews were conducted with 34 farmers and five extension officers (Derkyi et al., 2021). The maps were updated utilising the fieldwork. The preliminary results were presented at a workshop with diverse stakeholders, whose feedback, particularly regarding adoption drivers and enablers, was invaluable. This stakeholder feedback was integrated into the Bayesian network model to the extent permitted by data availability, leading to the production of an updated and more refined suitability map.

3. Case study on the Rhine-Meuse-Scheldt Estuary (Netherlands)

3.1 Rhine-Meuse-Scheldt Estuary (Netherlands)

The case study analysis is focused to the southwestern part of the Netherlands, where the Rhine, Scheldt, and Meuse flow into the North Sea (Figure 2). In Dutch water policies, this area is often referred to as the Southwest Delta (Van Alphen, 2016). Food production outside the selected area also depends on water management in these spurs of the Rhine-Meuse-Scheldt delta.

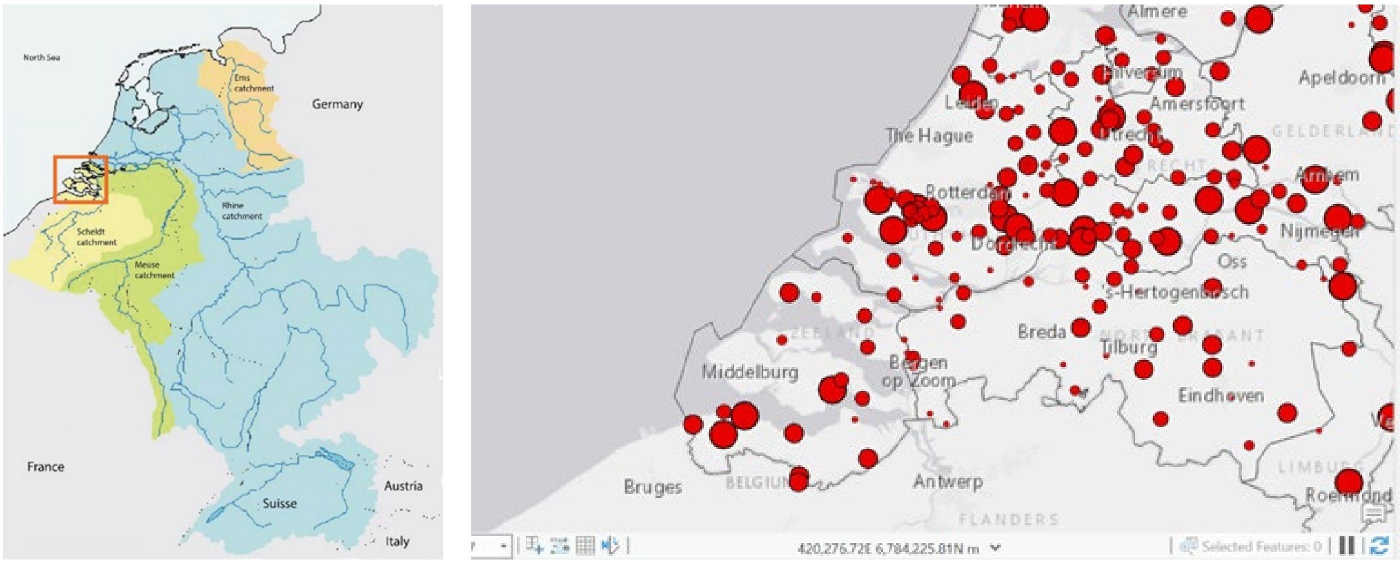


Figure 2. *Rhine-Meuse-Scheldt Catchments (left) with a cutout of the estuaries in the southwestern part of the Netherlands including wastewater resources derived from E-PTR data.*

Water supply – The Netherlands usually has a precipitation deficit in summer (average 100mm) and a precipitation surplus in winter. In the coastal zone, the precipitation deficit in spring and early summer is usually larger than in the rest of the country, whereas the situation is reversed in late summer and autumn (Van Minnen & Ligtvoet, 2012). The annual cumulative maximum precipitation deficit occurs during the summer half-year from April to September (Beersma & Buishand, 2004).

Under average climatic conditions, the freshwater supply for Dutch agriculture is excellent. However, in situations with a low river discharge and a high precipitation deficit, the freshwater supply cannot meet agricultural freshwater demand during the growing season, as we experienced in 2018, 2019, and 2022. This is particularly true for the rainfed agricultural areas in the southwestern part of the Netherlands that have no access to river water.

Reuse of effluent water could, potentially, reduce the gap between water supply and water demand. However, not only is the reduced gap in volume important, but also the water quality if the water is reused for food production or is discharged in nature areas (Pronk et al., 2021). Natural processes are explored in policymaking to solve this, such as the use of constructed wetlands to realise additional water for food production or drinking water production by purifying used water. However, competing land claims in the Netherlands are a barrier to realize these type of landscapes (Gupta et al., 2016). That is why in this study combinations of nature-based solutions with wastewater treatment technology are explored. Food processing industries in the Netherlands are also exploring how water use per unit of produced product can be reduced. Some consider whether residual water streams can be re-used within the factory or by neighbouring landowners such as farmers. Also, food processing industries investigate whether substances dissolved in the water can be re-used.

Food Supply – Agriculture in this area contributes to Dutch economy by food production for consumption in the Netherlands and the export of agricultural products. The physical yields in arable farming have increased enormously over the past century. In an economic sense, the contribution of Dutch Agro- and Food sector was near 7% of the GDP in 2020, of which 30% can be attributed to the primary sector (WECR, 2022). In 2021, the annual export of agricultural products had a value of approximately €105 billion (Jukema et al., 2022). In the case study area, there are about 5,500–6,000 agricultural entrepreneurs of which 50% perform arable farming, 12% horticulture, and 6% greenhouse horticulture (CBS & LEI, 2014). This is about 10% of the total number of farms in the Netherlands.

Environment – In the case study area, the rivers Rhine, Meuse, and Scheldt come together. The interplay between sea and rivers is controlled by a comprehensive system of protective dikes and storm surge barriers developed between 1953 and 1997 to reduce flood risks. These measures have caused water quality problems and unforeseen ecological shifts. The result is that the water bodies in this region still do not comply with Natura 2000 and Water Framework Directive, despite environmental policies (van Gaalen et al., 2020; Veraart et al., 2021). European environmental regulation also requires that the treatment process in a constructed wetland, if it is part of a wastewater treatment unit, continuously functions, despite extreme events or natural dynamics. When the food processing industry and farming activities become less dependent on freshwater (surface water) from the delta, more water resources are left for nature, which in delta areas creates options to restore or protect estuarine dynamics.

Socio-economic institutions – In the Netherlands, there are subsidies for the agricultural sector and food industry aimed at making food production more sustainable, such as VAMIL (depreciation of environmental investment), and the more efficient use of natural resources such as water and rural development. There are subsidies from the government (e.g., Delta Fund), the European Commission (CAP), and regional authorities sometimes have funds. The subsidies often cover only part of the investment and entrepreneurs must make it clear that they are making the investment for the benefit of the public interest (environment), not for profit. A subsidy can act as an enabler, but also as a barrier when the application procedure is too complex or the private benefit for the entrepreneur is too small.

Reuse of wastewater (NbS) and available alternatives – Food processing industries in the Netherlands are increasingly exploring how water use per unit of a produced product can be reduced in both raw materials supplying farming systems and within the factory. Some industries are considering whether residual water streams can be reused within the factory or by neighbouring landowners (e.g., horticulture, livestock, onshore aquaculture, cattle). Also, valuable substances dissolved like nutrients in the water can be re-used. In turn, the food processing industry can also use residual flows from other sectors. Natural processes can also be the basis for wastewater treatment, such as constructed wetlands. Wastewater purification can consciously utilise ecological nutrient uptake processes and sedimentation of suspended solids that can observed in aquatic ecosystems. In constructed wetlands, these uptake processes can be optimised (Saaltink et al., 2016; Wagner et al., 2018). It depends on the design whether regional biodiversity can also benefit of these constructed wetlands. The flipside is that the competition for land is high in the Netherlands, making it more difficult to realise constructed wetlands. In the case study area, there are alternative freshwater resources available. The climate resilience of those freshwater resources are the subjects of research (Mens et al., 2022), including re-use of water (Pronk et al., 2021). Currently, there is a choice between precipitation (winter surplus), river supply, and groundwater sources in the case study area (Figure 5), except for the southern part of Zeeland where no river supply is possible and limited access to groundwater.

3.2 Case study Bono East Region (Ghana)

The Bono East region is a part of the former Brong Ahafo region in Ghana (Figure 3). The region lies in the transitional zone from Savanna to temperate climate and the green vegetated belt in Ghana. The Northern and Northeastern regions are Guinea savannah woodlands, transitioning to semi-deciduous forest in the South-West area. The Techniman North District is one of the districts of Bono East Region, which is favourable for applying rainwater harvesting techniques for farming.

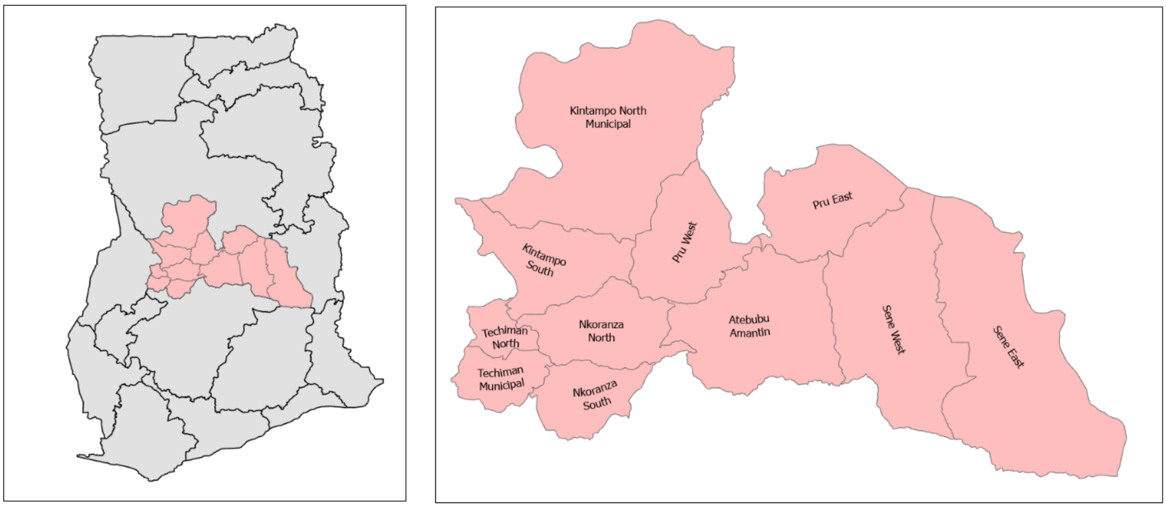


Figure 3, *Ghana (left) emphasizing Bono East Region and a cutout of the Bono-East Region showing its districts.*

Food Supply – The Bono East Region in central Ghana represents a rural region which is known for its food production. The region is commonly referred to as one of the major ‘food baskets’ of the country which provides a large proportion of food consumed in Ghana’s major cities Kumasi and Accra, as well as its neighbouring countries. Its dependence on agricultural production is its strength, yet at the same time also its weakness, as the mounting pressure on arable land is increasingly leading to disclosure of forested areas, with deforestation and land degradation as a result. Global climate change is even acerbating this situation, as it leads to unpredictable crop yields, endangering livelihoods within the region and food security in Ghana as a whole (Läderach et al., 2011; the Ministry of Foreign Affairs of the Netherlands, 2018). The Ghana National Climate Change Adaptation Strategy (NCCAS) has the primary goal of *“enhancing Ghana’s current and future development to climate change impacts by strengthening its adaptive capacity and building resilience of society and ecosystems”(Government of Ghana, 2021).* It is expected that agriculture, which is the largest employer in Ghana, will be heavily affected by the increased variability of rainfall, with devastating impact on crop yields, productivity, and farm income. Besides increased variability of rainfall, the average temperature is also on the increase, causing prolonged droughts and more frequent incidence of bush fires, with environmental degradation as a result (Government of Ghana, 2012, 2021). Vulnerability to climate change in Ghana is spatially and socially differentiated whole (Läderach et al., 2011; the Ministry of Foreign Affairs of the Netherlands, 2018). In the transition zones, the variability of rainfall has serious consequences for farmers and the remaining forests, as the changing weather conditions affect the production of cocoa and fruit, such as pineapples, mangos, papaya, etc. (Government of Ghana, 2012).

Water supply – Over the past few years, water supply in Bono East Region has become irregular and unpredictable. It is becoming harder to predict the onset of the rainy season, while erratic rainfall and prolonged dry spells have turned agriculture into an unreliable and unprofitable activity. In the adjacent Northern Region, the rainfall patterns have changed even more dramatically, putting pressure on Northern animal husbandry practice. Herders are therefore moving southward, putting more pressure on the increasingly scarce resources in Bono East. The resulting heat stress, periodic lack of water, pests, and diseases are on the increase. To cope with these climate-induced challenges, farmers have become even more dependent on the natural resources they have, not only through intensifying their agricultural and animal husbandry activities, but also by increasing their use of naturally occurring trees for timber, house construction, and charcoal production. Illegal chainsaw operations in forest reserves and otherwise encroachment into forest reserves is increasingly leading to conflict between farmers, pastoralists, and forest dependent communities.

Solutions & alternatives – There are several techniques that would help farmers to adapt their management practice to the changing weather conditions, but so far, in Bono East these techniques are hardly practiced. One example of this is rainwater harvesting for irrigation, which is frequently practiced in the North, where it has provenly enhanced the climate-resilience of the food system future (Boelee et al., 2013; Stockholm Environment Institute & United Nations Environment Programme, 2009). However, rainwater harvesting is not yet common practice in the Bono East variability (Amankwah & Napoleon, 2019; Antwi-Aygei, 2012). This may be explained that the effects of climate change are not yet fully perceived or practically experienced, leading to a low sense of urgency among producers and policymakers. Climate projections however show that this situation will change very soon. This may however change in future, as rainwater harvesting is a good option for rural communities to get safe water for domestic use given the limited access to public water supply (Antwi-Aygei, 2012; Owusu & Asante, 2020). It allows for the collection of run-off water, storage of it, and making it available where and when it is needed, as it is stored and kept for a later moment in time (Kiggundu et al., 2018; Qadir et al., 2007). Moreover, RWH can be part of soil and water conservation measures to increase agricultural productivity (Abdallah et al., 2014). In 2011, the National Rainwater Harvesting Strategy for Ghana was published (MoWRWH, 2011). One of the statements in this strategy was that the Ministry of Food and Agriculture (MoFA) and Ghana Irrigation Development Authority (GIDA) are responsible for developing irrigation reservoirs that harvest rainwater for agriculture (MoWRWH, 2011). Since 2011, the MoFA has worked on RWH for irrigation through irrigation schemes, but despite the potential, little of these investments have been made in Bono East (Amankwah & Napoleon, 2019; Hari, 2019; Linderhof et al., 2022).There are multiple techniques that are available for rainwater harvesting, adapted to the context. Depending on slope and soil texture and structure, run-off of rainwater can be harvested from a catchment area into a reservoir created by micro-dams (Biazin et al., 2012; Kiggundu et al., 2018). Alternative techniques consist of rooftop collectors, underground tanks, wells, and ponds (Hagos et al., 2013). The different techniques require different levels of infrastructure and herewith different levels of investment. The choice for a specific technique depends on the feasibility, applicability, and financial possibility of the farmer or owner of the land. Figure 4 provides an overview of multiple techniques applied in Bono East.

Figure 4. *Three different techniques of rainwater harvesting for agricultural production. Source: (Linderhof et al., 2022).*

4. Results and discussion

4.1 Development and use of spatial information in the Netherlands

Development of spatial information

Initially, a water availability map (prototype) and a technology portfolio for wastewater reuse was developed for the southwestern part of the Netherlands. First, the agricultural water demand was calculated for each municipality in the region. The agricultural water demand is based on the potential transpiration, actual transpiration, and irrigation based on the current climate for the period 2009–2018 with outcomes for 10-day periods for 250x250 meter grids. To calculate the agricultural water demand, data is also required about the available surface area per crop type. For this purpose, the Land Use Database of the Netherlands (LGN7) was used (Hazeu, 2014).

Based on the E-PRTR data (EEA, 2020), an estimate has been made of the yearly potential supply of water (in m3) from industry and sewage treatment, using the reported phosphorus load as a proxy. In Figure 5 (section 4). the water supply (effluent) and water demand are superimposed with an outcome for each municipality in this region.

To get a first impression, we consider if reusable water resources are an option for an additional water supply in view of climate change in the current situation. It was explored in which areas the potential new water resource remains greater than the current water demand from agriculture. This provides a first picture in which municipalities the potential additional water supply in view of climate change is present or not. In the future, agricultural water demand (increasing evaporation and changed precipitation patterns), the crop choice, land use, and farm management and irrigation will also change. The scenario for the future were not available during the stakeholder consultations. Instead, the stakeholder consultations provided insights about the strategies to make use of the additional water supply in view of climate change. Ultimately, a map was made showing practical examples, mentioned by stakeholders, where water reuse is already taking place.

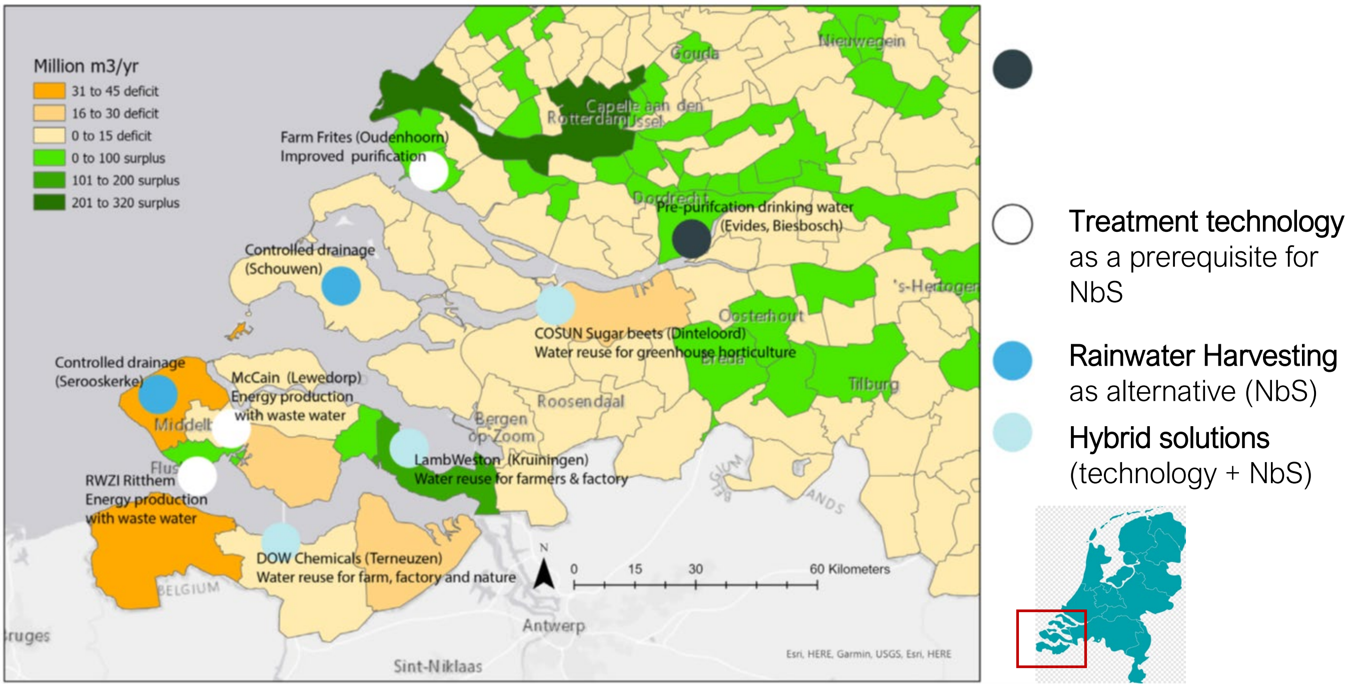


Figure 5. *Comparing wastewater availability with agricultural water demand in the southwestern part of the Netherlands at the municipal level (current climate), including practical examples (circles).*

The used spatial information

The green areas on the feasibility map of the Netherlands (Figure 5) are municipalities where the potential water supply from industry and sewage treatment exceeds the water demand from agriculture in the current situation. In these areas, it is interesting to explore whether this unused water resource can be an addition to the current available water resources (surface water, precipitation, groundwater). This potential water resource can be used within and outside the municipality in question.

The circles include examples where reuse of effluent is already practice, as mentioned by the consulted stakeholders. The stakeholders provided arguments as to why the example presented qualified as NbS. In our analysis, we grouped the examples (Table 4) and projected them on the map (Figure 5). In addition, we identified which technology or NbS could be considered for each cluster. It should be noted that the arguments, as mentioned by both stakeholders and experts, do not always match the definition we use for NbS.

Table 4. *Overview of the clustered examples from the stakeholder dialogue coupled with identified technologies.*

Cluster 1: Treatment technology is a prerequisite for NbS (micropollutants)	Cluster 2: Purifying Landscape: ecological processes as basis with optional technological support	Cluster 3: rainwater harvesting as an alternative for wastewater reuse in agriculture	Cluster 4: Hybrid solutions, combinations of (1,2,3) at regional level as a climate adaptation strategy
Technologies • Filtration (membranes) • (Reversed) Osmosis • UV-treatment • Thermal disinfection • Electrochemical treatment • Ion exchange	**Technologies** • (constructed) wetlands. • Soil Infiltration Areas • Benthos/worms/macrofauna	**Technologies** • Controlled drainage • Aquifer recharge • Dune and Creek ridge conservation (NBS) • Subirrigation	**Technologies** • Reuse water sugar beet factory COSUN

Treatment technology as a prerequisite for nature-based solutions (cluster 1)

Water Treatment processes, based on natural processes (e.g., uptake by vegetation or sedimentation), could be an effective measure to re-use water and nutrients. However, to reduce the emissions of micro-pollutants such as crop protecting agents (CPAs), PFAS, and pharmaceuticals and medicine residues these processes in (constructed) wetlands are not suited. So called 'polishing technologies' are needed, however, the disadvantage of these technologies, based on oxidation and/or ozonation processes is that they are not selective. Also, the natural occurring organic material (NOMs) in the effluent are oxidized. This organic material is important for the food web of wetlands, degradation has consequences for biodiversity when the treated water is intended for nature areas (Overbeek et al., 2018). Our hypothesis is that by establishing hybrid solutions consisting of both NBS and technology best of both worlds is reached and quality and quantity can be guaranteed.

Purifying Landscape, a nature-based solution with optional support of technology (cluster 2)

Organic matter and nutrients can be removed by ecological processes, but not always in the desired quality for economic use. Technology can lend a hand if the purified water must be of constant quality for people and/or nature. Pre-purification (five months) of water from the river Meuse in water reservoirs was identified as a NbS by Evides, one of the participating drinking water companies. Those water reservoirs, located in the Biesbosch, are in use since the seventies of previous century. Pilots are currently conducted at other drinking water plants to improve those systems (Caltran et al., 2020).

Rainwater Harvesting as an alternative for water reuse (cluster 3)

Several workshop participants have mentioned Rainwater Harvesting as an alternative for wastewater reuse, while in Ghana the stakeholders identified mainly barriers for adopting this solution. Those participants referred to research pilots based on infiltration of rainwater into soils or aquifers (Pyne, 2005) in arable farming, fruit cultivation, and horticulture in Zeeland (Figure 5). Those research pilots make use of technologies such as controlled drainage, storage, and infiltration of freshwater in creek deposits with controlled drainage systems (Pauw et al., 2015) and aquifer storage and recovery (ASR) technology (Pyne, 2005; K.G. Zuurbier et al., 2014; K.G. Zuurbier et al., 2014).

Hybrid solutions (cluster 4)

We also identified examples, that are combinations of cluster 1, 2, and 3. Those examples, already in practice, concerned cooperation between different parties involved in food production (e.g., farmers and food processing industry). It concerns several private parties that have made agreements on a regional scale about the exchange and storage of used water. One of these examples concerned a sugar beet factory in Dinteloord (Figure 5). Wastewater from this factory is used as irrigation water for nearby greenhouse horticulture. The treatment is done by Reversed Osmosis. Sugar beets are processed in autumn and winter, while Greenhouse horticulture needs irrigation water in spring/summer. Since 2016, the purified waste water is stored within the aquifer during winter and the water can be recovered in spring and summer by ASR technology (K.G. Zuurbier et al., 2014).

Discussion

- We observed that the provided spatial information about water supply was confirmed or disputed by participating policymakers, while the involved entrepreneurs took it for granted. For example, policymakers were concerned that in regions with creek ridges the agricultural water demand (irrigation) was overestimated in this map. In reality, the climate resilience of agricultural water demand is higher than modelled, explained by the natural phenomenon of rainwater lenses (De Louw et al., 2011).

- The geographically defined borders to compare water supply and demand based on maximum acceptable transport costs of water (pipes), as initially used, was difficult to grasp for stakeholders. Therefore, we have scaled up these units to the areas of the municipalities.
- Security of supply is more important to private parties than the underlying principle (nature-based, technical, etc.), while the consulted policymakers consider a nature-based solution as an important added value. NBS solutions are also initially considered in the Netherlands, but finally not implemented. For example, the Heineken brewery considered biological wastewater treatment (Helophyte filter). However, it was decided to postpone the project, because it appeared difficult to guarantee the desired discharge water quality towards the authorities.
- Not only water is a recyclable resource from wastewater, also the reuse of the dissolved substances has an economic value was brought forward by the consulted entrepreneurs. For policymakers, this was more seen as a side effect.

4.2 Development and use of spatial information in Ghana

Development of spatial information

Uptake and scaling the multiple types of rainwater harvesting not only depend on the potentially suitable areas available within a specific landscape, but also on the biophysical, climatic, and socioeconomic drivers at hand (Duku et al., 2021). Identifying these different drivers in Bono East was done with the aim to develop a suitability map for rainwater harvesting by building a Bayesian belief network, based on a combination of criteria defined in the literature (Adham et al., 2016; FAO, 2003; Haile & Suryabhagavan, 2019), and feedback from stakeholders in a workshop setting. The outcome of this exercise shows that rainwater harvesting for irrigation in Bono East is often randomly implemented, without considering the wider ecological, socio-economic, and institutional context. This leads to sub-maximum use of Bono East's potential, and poor performance of investments made. Identifying the potentially promising areas where rainwater harvesting for irrigation could be successfully implemented as a function of bioclimatic, terrain, hydrologic, and edaphic factors, hence well-embedded in its spatial context would be an effective pathway to enhance climate resilience, more efficient water use, and stronger circularity of food systems.

Spatial information used

Figure 6 shows the feasibility map which reflects the probability that an area is suitable for RWH for irrigation in Bono East. Suitability was computed using Bayesian belief networks as a function of slope, soil hydrologic properties, mean annual rainfall, tree cover, land cover, and distance to farms.

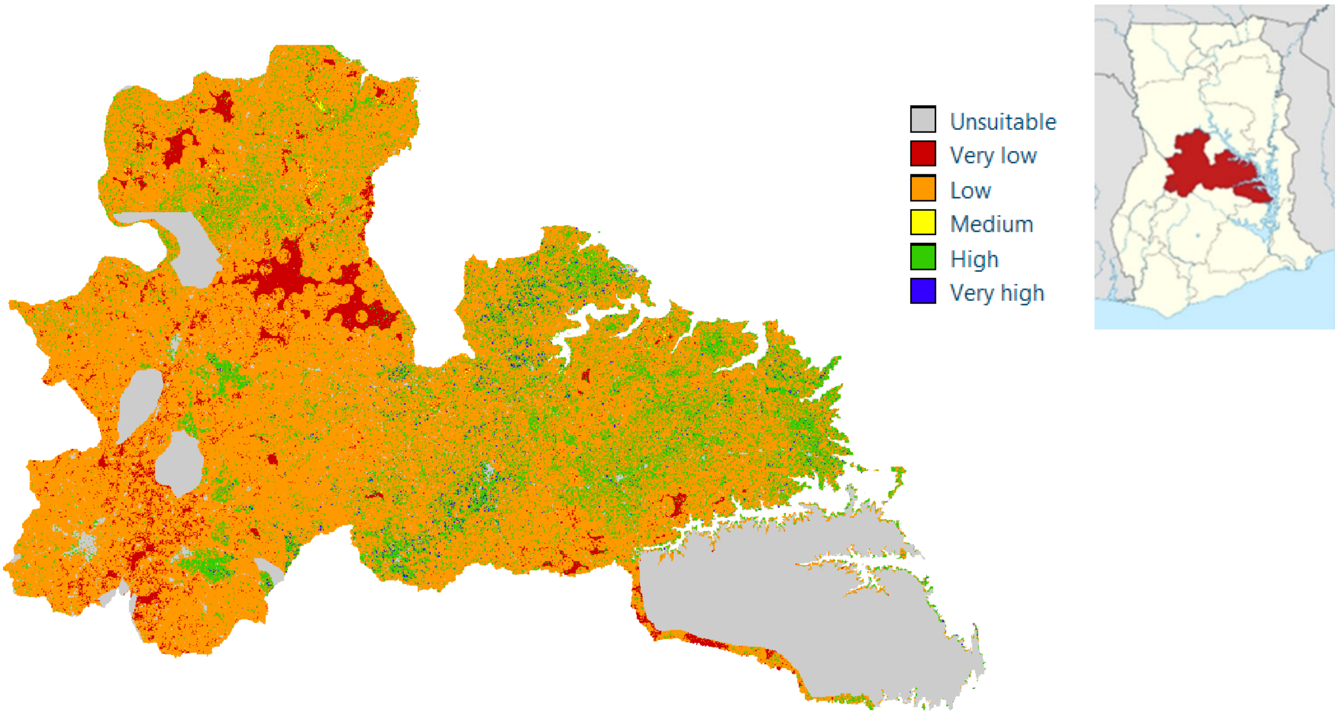


Figure 6. *Suitability map of RWH for irrigation in the Bono East Region (Duku et al., 2021).*

Discussion

We found that whereas awareness on climate change is mounting, the sense of urgency in Ghana's Bono East remains relatively low. Currently, there are few examples of rainwater harvesting for irrigation in the region, while the potential of it is high. But, even if the sense of urgency would increase, there still are several barriers to the uptake of rainwater harvesting that hamper this NBS to be applied. These barriers may be categorised in the following manner:

- Biophysical barriers: inaccessibility of the terrain; steep slopes; erosion and run-off; more pronounced seasonality of rains.
- Technical barriers: poor availability of technical solutions; poor availability of knowledge to apply technical solutions.
- Socio-economic barriers: low motivation of farmers to invest; lack of financial means to invest; low-income level of farmers; unclear ownership of land, which is a disincentive to invest; low level of farmers' organisation, making it hard for farmers to invest collectively; stakeholder conflicts related to access to and control over resources such as water and land; pastoralists using water sources for drinking.
- Institutional barriers: available means for RWH are channeled through the Ministry of Social Services taking care of water and sanitation in town; not through the Ministry of Agriculture that takes care of agricultural production and irrigation; poor policy alignment; lack of farmers' participation in sectoral and spatial planning; poor access to spatial information and lack of participatory spatial planning methodologies.

Despite all these barriers, stakeholders believe that there is the need for RWH for irrigation, and the potential for it in Bono East is high. Through interviews, focus group discussions, and stakeholder dialogue, there was created a theory of change of the social, economic, and environmental impacts of RWH for irrigation implementation in Bono East, the impact on the food system using the food system framework and the stakeholders were listed (Linderhof et al., 2023). The following enablers were recognised:

- Biophysical enablers: the strongest enabler is the climate itself. It is increasingly acknowledged that rain events are getting increasingly erratic, which is increasingly affecting agricultural yields. This increased awareness raises the sense of urgency, which is a great enabler for actors to develop the agency to respond.
- Technical enablers: There is technical knowledge available in Ghana, as the results show that rainwater harvesting is commonly practiced in the northern part of the country, which is much drier than the Bono East Region. Scaling the northern experience towards the south is very feasible, but needs to be supported by agricultural extension services, governmental or non-governmental support agencies, farmers' associations, and farmers themselves.
- Socio-economic enablers: investment in rainwater harvesting requires financial means which are typically low. Nevertheless, as Bono East Region is the food basket of Ghana, which will only increase under future climate conditions, leading to higher prices of food. It can be expected that this will lead to higher prices, which theoretically enables farmers to intensify commercial food production, earn more, and invest more. The issue of land ownership, however, remains a challenge, as unclarity on property rights are a disincentive to invest. Therefore, strengthening tenure security, land certification and cadastral developments will stimulate commercialisation and herewith increase the uptake of RWH for irrigation.
- Institutional enablers: integrating RWH for irrigation in the various sectoral policies can only be possible within a framework of stronger policy integration, and intersectoral spatial planning. Aligning Social Services policies with agricultural policies would help bringing RWH for irrigation infrastructure closer to the farm areas, to reduce investment costs. Enhancing urban water supply could reduce the pressure on surface water and enable farmers to get access to rainwater harvesting investments and support. Moreover, increased access to spatial information and participatory spatial planning methodologies would increase farmers' participation in spatial planning, bringing their needs and interests to the fore.

4.3 Differences and similarities in the spatial approach

Our observations on the use of spatial information in Ghana and the Netherlands are summarised in Table 5.

Table 5. *Difference and similarities between the Netherlands and Ghana regarding the use of spatial information in this research project for the identified contextual conditions (Table 1)*

Contextual conditions	Spatial information about:	Netherlands	Ghana
Water supply	• Water Gap Risk (supply < demand) • Adaptive capacity to climate change	• Assessed for the current climate and spatial information was improved in consultation with stakeholders	• Assessed for the current and future climate and used in stakeholder participation
Food Supply	• Food Gap Risk (Supply < Demand) •	• No spatial information was provided and involved stakeholders did not express spatial explicit information need on this subject.	• No spatial information was provided; however, stakeholders did emphasize the need for spatial explicit information need on this subject.
Environment	• Biodiversity • Soil	• Spatial information about the soil was implicitly provided/available as it was used to calculate the	• Spatial information about the soil was implicitly provided/available as it was used to

		water demand. Involved stakeholders were concerned about the soil health and have access to soil information. • Spatial information about the impacts of biodiversity was not provided. Involved stakeholders did not express needs on this subject. However, from other studies in the Netherlands it is known that this need exists (Pronk et al., 2021; Zuurbier et al., 2018).	calculate the water demand. Involved stakeholders did also express knowledge needs that require spatial information on soils. • Spatial information about the impacts of biodiversity was not provided. Involved stakeholders did not express needs on this subject.
Socio-economic & institutional	• Land tenure • Policy incentives and support	• Spatial information on land tenure is not publicly available, but can be made available on request (cadaster). This information was not used. Involved stakeholders did not express spatial information needs about land tenure, but the involved organisations use information about land tenure when granting permits for irrigation and drainage, for example. • Spatial explicit information on policy incentives is publicly available but was not explicitly provided in this study. Stakeholders expressed information needs but those were not spatial explicit.	• Land ownership was an important criterion of constructing the suitability maps. However, this information was not publicly available. • Although RWH is stimulated by Ghanian Government, this policy is not yet applied at Bono East Region since the lack of water availability during growing season has not yet reached a critical level. Spatial information on suitable places for RWH would be beneficial for RWH policy in Bono East Region.
Alternatives for NbS (Rainwater Harvesting & Water reuse)	• Available alternatives • Added value NbS for Food System • Income Effect for Farmer from NbS	• Examples of alternatives, derived from the stakeholder consultation, were provided on a map (Figure 5) for future stakeholder processes. The involved participants expressed needs for spatial explicit information on this subject, but also provided information.	• Alternatives for NbS could be changing cropping patterns towards more drought-resilient crops. However, giving the fact that Bono East Region supplies food to urban areas (Accra and Kumasi, for instance). Current food supply consists of stable crops contributing to food security of low-income people in the urban areas. The

			consequences of changing cropping patterns are uncertain for people in Bono East Region and in urban areas.

Discussion

Ghana

The actual choice for specific technical options were in Ghana not explained by technical and contextual factors alone, but also by the availability of spatial information to make a well-informed choice, as well as the way in which spatial information was communicated and used by a variety of stakeholders in the form of participatory spatial planning. The case study used online and offline stakeholder dialogue and scenario modelling to assess suitability based on biophysical data, as well as socio-economic and institutional data, both types of data being key in mapping suitability and making well-informed choices. Both the online and offline dialogue offered a safe space to raise awareness on the necessity for NbS, discuss the different alternative solutions, and share insights on how best spatial data can be made available, to serve stakeholders to make a well-informed choice.

The Netherlands

In the Netherlands, the spatial information about additional water supply and demand provided insights for stakeholders to discuss also alternative solutions to combat the impact of climate change on water supply. Spatial information was initially used in the Netherlands to identify the best places for the application of the NBS at stake (reuse of wastewater).

Similarities in use of spatial information

In both cases, the use of geo-spatial information was considered as a stimulus to adopt and apply NBS, making the researchers realise that the role of geo-spatial information in the adoption and application of NBS is important. It helps to analyse the impact of climate change and present the NBS as an effective measure to adapt and raise the awareness on the potential of this.

In both case studies, the effect on biodiversity of respectively reuse of effluent water and RWH did not play a direct role in the stakeholder dialogue. Attention was rather paid to the economical use of natural resources (water, soil, nutrients in both case studies). Spatial information about the soil was used in both case studies, but no spatial information about biodiversity was available nor used.

5. Conclusions

Water-related problems connected to climate change are threatening the future of food systems in both the Netherlands and Ghana. The studied NbS offer opportunities for adapting to the impacts of climate change and increase the efficiency of water use in food systems. We studied two ways in which this can be done: making better use of rainwater by harvesting rainwater and reusing water through wastewater treatment. The first solution, as applied in Ghana, directly relates to rainfall, it collects the water whenever it falls, and requires relatively low investment costs, which need to be covered by increased crop yields. It increases a one-off efficiency in water use and does not allow for re-use. It also responds to climate change through adaptation, but it is less relevant for circularity, which is not yet an issue in Bono East. It requires relatively low investment costs, which suits the context which allows for small investments only, based on low rentability, low farmer incomes, and low levels of industrialisation involved.

The second solution, wastewater treatment, is focusing on recycling water, by using it more than once. This solution also responds to climate change by adapting, but it also allows for a more circular food system to emerge and is much more dependent on technology and associated investment costs. It does, however, depend on technological innovation and requires considerable investment costs. It is, therefore, more likely that this NbS is adopted within a high value food system context, where food production and processing is industrialised and has high economic returns.

Both types of NbS respond to the challenge of climate change and farmers to adapt. Both rainwater harvesting and wastewater treatment techniques are available, and ready to be accepted and applied by farmers and food processing industry. Their uptake, however, is hampered by multiple barriers, ranging from biophysical and technical barriers to social and institutional barriers.

In both cases, the availability of spatially explicit information, in combination with sectoral policy integration and more participatory spatial planning is considered key in adopting the available technology. The objective of this analysis was to identify differences and similarities in the use of spatial information by experts and stakeholders in their attempts to remove the barriers or foster the enablers of NbS uptake. We conclude that the following requirements are essential to develop spatial explicit scenarios for NbS for climate resilient and circular food systems:

- Spatial information can be an enabler for adoption of nature-based solutions, if the spatial information is applicable for the assessment of a wide range of possible solutions for water scarcity considering food production, either nature-based solutions or technologies.
- In both case studies, we observe a struggle to make the future spatially explicit. In the Dutch example, it helped to discuss the future with existing examples (enabler), but the test of whether the potential water supply is climate-proof remains essential for existing subsidy regulations and is still missing (barrier).
- In both case studies, the effect on biodiversity of respectively reuse of effluent water and RWH did not play a direct role in the stakeholder dialogue. We were not able to identify whether this is an enabler or barrier for adoption of RWH for irrigation and wastewater reuse in food production and water management respectively. However, it is recommended to investigate this. Furthermore, biodiversity, in particular soil biodiversity, can also be a factor that determines the suitability of an area for both.

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