NATURE-BASED SOLUTIONS FOR WATER MANAGEMENT IN THE PERI-URBAN: ECOLOGICAL, SOCIAL & ECONOMIC NEXUS

Report to the
Water Research Commission
compiled by
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WATER RESEARCH COMMISSION

NATWiP

Water JPI

Image credit: Cape Winelands Biosphere Reserve; the Langrug Informal Settlement demonstrating water-related challenges

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Executive Summary

Nature-based solutions (NBS) are defined by the IUCN as "*actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (IUCN, 2020). These solutions are considered to be "*inspired by, supported by or copied from nature*" (European Union, 2015). Underpinning NBS is the protection and restoration of ecological infrastructure, a term referring to "*the underlying framework of natural elements, ecosystems and functions and processes that are spatially and temporally connected to supply ecosystem services*" (Dominati, 2013). A critical question is How can we increase adoption of nature-based solutions at scale within development practices? This question is especially pertinent to address water-related challenges within peri-urban zones. We focus on the assessment of nature-based solution case studies by applying a collaboratively developed Framework that incorporates a nexus of sustainability parameters, including ecological, social and economic dimensions.

This research aimed to move beyond the state of the art by taking a systemic perspective on nature-based solutions for water, with an emphasis on complexity, uncertainty, resilience and adaptation for different peri-urban contexts. It focussed on the need to ensure the involvement of multiple stakeholders and combine multi- and transdisciplinary knowledge as key elements in the implementation and assessment of nature-based solutions as local responses with replicability potential. This is intended to make progress towards a new management paradigm for peri-urban areas.

This Water Research Commission (WRC)-funded research is part of an international research project called: "Nature-Based Solutions for Water Management in the Peri-Urban (NATWiP): Linking ecological, social and economic dimensions", which is part of the Water Joint Programming Initiative. The NATWiP Project aims to contribute to closing the water cycle gap by exploring the potentials that nature-based solutions offer to address water management challenges in the peri-urban. The South African team, as part of this WRC-funded project, worked collaboratively with the international consortium on this project, contributing to six objectives, specifically to: (1) conduct an analysis of South African case studies, (2) write case study briefs, (3) write a narrative report on the main challenges for implementing nature-based solutions, (4) assist in the production of a policy brief, (5) write popular science publications for the case studies, and (6) assist in the production of a handbook for practitioners that can promote and inspire implementation of nature-based solutions in the peri-urban. The international consortium comprised an all-woman team of researchers from Södertörn University, Sweden (the coordinator); Centre for Conservation and Sustainability Science, Brazil; Universitat Poltècnica de Catalunya, Spain; Norwegian Geotechnical Institute, Norway; A.N. College, India; and Stellenbosch University, South Africa.

Study sites

Two nature-based solutions case studies were selected: (1) The Wildlands Trust, Dwars River alien tree clearing project, and (2) the Genius of SPACE (Systems for People's Access to a Clean Environment) green infrastructure project, Langrug. Both sites occur within the Upper Berg catchment in the Western Cape of South Africa. The Berg River is approximately 285 km long from source to sea, with a basin area of approximately 9 000 km^2. Both locations fall within the jurisdiction of Stellenbosch Municipality.

The Genius of SPACE project was a pilot project aimed to apply nature-based solutions (NBS) to treat and manage wastewater and greywater entering the stormwater system, as well as the management of solid waste while empowering local community members, improving living conditions and promoting social upliftment. Langrug, South Africa, is a relatively recently formed and continuously growing informal settlement (slum), where wastewater and solid waste accumulate in the streets due to lack of service provision, sewerage, and surface hardening, leading to localised flooding, disease risk and associated health issues. The Stiebeuel River drains the Langrug Catchment (about 4.37 km^2) and enters the Berg River, an important agricultural river for the Western Cape (predominantly winter wheat, vineyards, and fruit) entering the sea at the Velddrif Estuary (St Helena Bay), supporting important fisheries. Therefore, the eutrophication and pollution of the Berg River causes issues for agriculture downstream, which is particularly important because of the stringent growing and import standards of overseas trading partners. The NBS involved installation of 27 greywater disposal points, underground wastewater pipes, permeable paving, grading and pavement construction and 15 tree gardens for water infiltration.

The Wildlands Trust has been coordinating several riparian rehabilitation projects along the Dwars River, a tributary of the Berg River in the Western Cape, South Africa since August 2018. The Dwars River is heavily transformed, with landcover converted to predominantly agriculture over the past 300 years (mainly viticulture and fruit), an inter-basin transfer out of the catchment affecting the hydrological regime, and these disturbances *inter alia* resulting in infestation of the riparian zone by invasive alien trees and weeds. These invasive alien trees consume high volumes of water, reducing water supply, increasing fire risk, and negatively impacting biodiversity. The nature based solution implemented by Wildlands Trust involves three approaches: (1) the clearing of invasive alien trees, shrubs and weeds from the riparian zone (initially through logging operations, with follow-up clearing), (2) active rehabilitation of the riparian zone, through the planting of indigenous tree seedlings, and (3) engaging the community through creating employment opportunities in the rehabilitation programme, as well as a recycling and native tree growing programme, aimed to keep the river clean, in exchange for rewards (e.g. bicycles). This nature-based solution takes a socio-ecological systems approach and aims to improve hydrological flows (increase water availability) as well as engage the community, and indirectly – if implemented at scale – may improve water quality (dilution effects). The scale of the implementation is currently relatively small (small sections/strips of riparian zone along the river) and therefore the benefits of these interventions are mainly local and difficult to quantify.

Methodology

This study used a social-ecological systems approach to understanding nature-based solutions for water management in the peri-urban. We used a method co-developed by the international NATWiP consortium to assess the sustainability of nature-based solutions. This NATWiP framework and its application are detailed in the Handbook (Section 2.2). The NATWiP nature-based solutions Framework proposed by Lima *et al.* (2022) recommends the identification of relationships between the sustainable development goals and the nature-based solution project objectives. These sustainability goals are aligned with the three sustainability dimensions (environmental, social and economic); and they are applicable to peri-urban areas and other settlement types. Importantly, it is a flexible and adaptable framework that can be used in different spatial, social and environmental contexts.

To apply the methodological framework designed by the NATWiP project team to the two South African case studies, ethical approval was obtained and the framework was then converted into an interview schedule for both implementers and community members. This resulted in two separate

interview schedules for implementers and community members for each case study. To assess the context, process, and results of the nature-based solutions in the two South African case studies (in line with the framework), projects were assessed in relation to the ecological, social and economic dimensions of sustainability. These interview schedule templates were further slightly adapted to the specific case of the Genius of SPACE and Dwars River Projects.

Implementers were interviewed (target: 5-10 individuals from different organisations) between January and March 2021 via a virtual platform such as Zoom, using a snowball approach starting with recommendations of the main nature-based solution project implementers at each case study site. The interviews were conducted by members of the South African research team in English and recorded. The recordings were transcribed and then analysed.

Community members were approached via community leaders, also on recommendation of the main nature-based solution project implementers at each case study site. We targeted 20 individuals from each community and tried to cover a diversity of people (age, gender, race, land ownership type) where possible. A physical meeting was arranged, and costs covered to offset any travelling costs or compensate for time. To minimise travel costs, community members were met at a safe, central location for interviews, at a library community hall and school hall in the Dwars River, and at a library seminar room in Langrug. Covid protocols were observed at all times. Interviews were conducted in Afrikaans and isiXhosa and recorded, transcribed and translated into English, and then analysed. Please see the schedules in Section 2.3.

State of the art

We performed a global literature review on nature-based solutions for water management in the peri-urban, titled: "*What are the benefits of water-related investments into nature in the peri-urban? A Global South perspective*". With rapid urbanisation occurring globally, peri-urban areas (transition spaces often affected by expansion processes of the city) become increasingly important as a source of ecosystem services to people yet are increasingly degraded. Nature-based solutions have been proposed to tackle many societal challenges, such as declining water quality, air quality and food security. Their advantage over traditional hard infrastructure solutions is thought to be in their ability to provide "co-benefits", or additional benefits.

Despite the value of nature-based solutions, and the strategically important location of peri-urban areas, there is no synthesis on the benefits of implementation in these settings. With the rapid expansion of cities in the Global South, there is a need to understand what has been implemented in these nations, as well as what the impacts have been. In this study we systematically review the global peer-reviewed English-language literature and the South African grey-literature as a Global South case study. We endeavour to synthesize the benefits (also co-benefits), the quality of the evidence, and develop insights from exploring this from a Global South perspective.

We found that the Global South's representation in international literature is low. The benefits of nature-based solutions in peri-urban areas were mostly found to be positive. However, in general, nature-based solutions are not well empirically studied (many studies are conceptual or descriptive). Very few publications explicitly addressed the topic of co-benefits. Some important insights emerged by incorporating the Global South case study.

Funding and governance are serious barriers for implementation for the Global South, compared to technology and innovation for the North. Benefits were disaggregated by socio-economic status and gender for the Global South and location for the Global North. Including the Global South perspective has widened the narrative and yielded important insights which advances the growing field of nature-

based solutions. We make some recommendations for future research to strengthen the field of practice of nature-based solutions, with reference to the peri-urban.

Results

Genius of SPACE case study

The Genius of SPACE nature-based solution involved the installation of 27 greywater disposal points, underground wastewater pipes, permeable paving, grading and pavement construction and 15 tree gardens for water infiltration. Semi-structured interviews were conducted with both Langrug community members (n=23) and actors involved in the implementation process (n=10) to assess whether the project was successful and what the major barriers are when implementing nature-based solutions in such contexts. The project was considered a failure by implementers, largely because of socio-economic constraints (i.e. unsustainable funding mechanisms, social vulnerabilities, and lack of stakeholder support). Despite considerable collaboration attempts between the community, the technical team and provincial government, sustained involvement from local government was lacking. The interdisciplinary nature of the NBS discouraged their involvement since government departments generally operate in sectoral silos. Furthermore, unsustainable, short-term, and cyclical funding mechanisms are challenging for NBS where benefits become apparent over longer temporal scales; this hampers acceptance by decision-makers with short-term goals and deliverables. Finally, the dynamics related to ownership rights and movement of people constrain community incentives to improve NBS. The second phase of the project was never realised, which was geared towards generating income and in turn, maintaining service provision. Despite these challenges, the project was somewhat successful in cleaning solid waste and the community experienced benefits regarding health and well-being, ecosystem service provision, education, and social cohesion.

Due to the challenges briefly described above, it was proposed that the experimentation of nature-based solutions is conducted in higher-income areas with greater capacities to cope with a failed system and that financing mechanisms are altered to overcome budget constraints experienced in the public sector. Despite the complex challenges, there was a sense of prosperity when the nature-based solution was functioning, and the community would like it to be reinitiated. Valuable lessons can be learnt from this case study to improve success in future applications, specifically in the context of the Global South.

The Wildlands Trust case study

This nature-based solution takes a socio-ecological systems approach and aims to improve hydrological flows (increase water availability) as well as engage the community, and indirectly – if implemented at scale – may improve water quality (dilution effects). The nature-based solution appeared to have had a very positive reception by the community, and good communication is cited as key in having achieved this. Many community members perceived improvements to nature (improvements in ecosystem services), which are experienced directly in terms of recreational benefits, improvements to aesthetics, and general well-being, social cohesion, and nature-connectedness. Any benefits in terms of augmented water supply or quality, though perhaps small due to the scale of the work, would be beneficial to downstream farmers who rely on the Dwars and/or downstream Berg River for irrigation.

In addition, using a mixed-method approach, integrating historical data, remote sensing techniques and stakeholder perceptions, we found that although anthropogenic land conversion happened primarily before the 1950s, several land use and land cover classes showed marked increases in area, including: waterbodies (+1074%), urban areas (+316%), alien weeds (+311%) and terrestrial alien trees (79%). These changes have likely been driven by land fragmentation, changes to the hydrological

regime, disturbance, and agricultural intensification. Stakeholder interviews revealed that despite the clear need for restoration, several barriers exist to successful implementation; these stem from inadequate financial resources, inappropriate funding models, institutional challenges, and a lack of techno-scientific knowledge.

Global narrative

The Project is part of a larger JPI research project with peri-urban nature-based solution case studies from several other countries and many project partners (see section 1.3). At the JPI mid-term meeting 2020, the South African team held a workshop with nine team members (participants) on 25 September 2020 with two aims: (1) to build a better understanding of all the case studies, and (2) to improve our understanding of the main challenges/barriers facing the nature-based solution implementation globally. We asked participants to describe their case study(s). We assigned three minutes per case study and asked participants to address the following four questions: (1) What is the main challenge(s) the nature-based solution is addressing?, (2) Is your nation developed/developing?, (3) What is the nature-based solution?, and (4) Describe/list the main challenges/barriers facing the nature-based solution implementation (considering ecological, socioeconomic, technological, political, legal, planning, governance, and institutional dimensions).

We then developed a survey, based on the results of the main challenges or barriers facing nature-based solution implementation for all JPI team members. This survey was completed in October and November 2020, and in November the results were analysed. We received responses from researchers from six nations and nine case studies. We found that suboptimal planning processes and sustainable funding emerged as the two greatest challenges in nature-based solution implementation, with lack of strategy, legal/policy context, rapid urbanisation and silo mentality also being highlighted as important. These findings are useful to inform future nature-based solution projects, as implementers will be able to anticipate possible risks and barriers and find strategic solutions in the planning phase.

Conclusion and recommendations

We have found that nature-based solutions for water management in the peri-urban yield valuable ecosystem services to society, as well as additional livelihood, social and economic benefits. However, the upscaling of these nature-based solutions is faced by several key barriers, and various enablers have been suggested to unlock this potential. These enablers suggest a socio-political context that would favour the implementation of nature-based solutions in the peri-urban at scale.

The main challenges for implementing nature-based solutions globally according to a workshop with the international project team are suboptimal planning processes and sustainable funding. Lack of strategy, legal/policy context, rapid urbanisation and silo mentality (fragmentation) also emerged as important. From the international literature review, inadequate financial resources, institutional fragmentation and path dependencies and inadequate regulations/policies or the enforcement thereof emerged as important. Additionally, a key barrier for nature-based solutions in the peri-urban was rapid urbanisation and development. From the South African Genius of SPACE case study, key challenges during the implementation included complex social and institutional issues including unsustainable funding mechanisms, social vulnerabilities, and lack of stakeholder support. For the Dwars River case study, stakeholder interviews revealed that despite the clear need for restoration, several barriers exist to successful implementation and that these stem from inadequate financial resources, inappropriate funding models, institutional challenges, and a lack of techno-scientific knowledge.

The top enabler that emerged from the global review of nature-based solutions in the peri-urban was stakeholder engagement and collaboration. This is a key feature that emerged in our South African

case studies as well, and investment into community engagement was highlighted by implementers as critical. A supportive policy context (i.e. plans, acts and legislations and the enforcement thereof) was also found to be an important enabler in peri-urban areas.

This study addressed a critical gap in the nature-based solution knowledge system, both in terms of focussing on the understudied peri-urban setting, but also in considering the Global South through a case study of South Africa on nature-based solutions for water management (both in terms of two case studies, as well as a review of the grey literature). We found that including the Global South perspective has widened the narrative and yielded important insights which advances the knowledge system of the growing field of nature-based solutions.

We propose recommendations for future research on nature-based solutions:

- More holistic measurement of the benefits of nature-based solutions (e.g. ecosystem services as well as social, livelihood and economic benefits) is needed for water management in the peri-urban (as opposed to focussing on one or two benefits in detail).
- More empirical research is needed on the ecosystem services and other benefits of agroforestry/urban forestry, agroecosystems/urban agriculture, combination, and ecosystem protection as nature-based solutions to water management in the peri-urban (as opposed to only theoretical/conceptual studies).
- In general monitoring was poor, as was field validation of modelling results. We recommend more field-based empirical research to support design of monitoring efforts and to quantify the benefits of nature-based solutions in the peri-urban and in other settings.

We propose recommendations for implementers and decision-makers around nature-based solutions:

- New planning mechanisms are needed that are more flexible and respond to the complexities of peri-urban areas, steering development towards sustainability.
- We recommend that implementers budget for a significant investment into community engagement, especially in communities that are socially vulnerable.
- We recommend that implementers budget for a significant investment into long-term monitoring.
- We recommend the development of new, creative funding models to finance nature-based solutions.
- We recommend more investment into nature-based solutions to solve water management issues in peri-urban areas, given the demonstrated benefits to society.
- We recommend a creative and supportive policy framework to support the integration of nature-based solutions into peri-urban developments.

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This research was ethically approved by the Stellenbosch University HSRC Research Ethics Committee (REC) (ethical clearance number: REC:SBE 13114).

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1. Introduction

This final WRC report describes the results of the international NATWiP Project from the South African perspective. Specifically, the report focusses on two of the project aims listed below (**section 1.2**), specifically 3 (3.1-3.2) and 4 (4.1-4.4). This report is therefore structured as a series of products which were compiled as part of the South African team's involvement in the international consortium. Therefore, although this report is structured in a logical sequence: introduction, methods, results and conclusions, each section is also a standalone unit. These standalone products are summarised in the main body of the report and provided in full as appendices (with their own references, and in some cases supporting material).

The report has five main parts: the Introduction (**section 1**) the methods (**section 2**), results (**section 3**), conclusion (**section 4**), recommendations (**section 5**) and includes references (combined from sections 1-5, **section 6**) appendices (combined from section 1-5, **section 7**). The introduction presents the problem statement of the NATure-based solutions for Water management In the Peri-urban (NATWiP) Project, the scope of the study, the project aims and outputs, the context of this research project, the team including the international consortium, and the main achievements. The methods section is composed of four parts: (2.1) a detailed description of the study sites, (2.2) the NATWiP handbook which details the conceptual framework used in this study, (2.3) the case study interview schedules which were used to conduct the interviews, and (2.4) a global literature review which will be submitted for publication in a peer-reviewed journal. The next section is results, and it is composed of three parts: (3.1) the narrative reports for the two South African case studies (one of which has been accepted for publication in a peer-reviewed journal), as well as workshop results on the global narrative, (3.2) the case study briefs for the two study sites, and (3.3) the photo stories for the South African case studies. In section 4, we conclude this study, and then list recommendations in section 5. We include some information on project achievements in the Appendix.

1.1 Problem Statement

With rapid urbanisation occurring globally, peri-urban areas (transition spaces often affected by expansion processes of the city) become increasingly important as a source of ecosystem services to people yet are increasingly degraded. Nature-based solutions have been proposed to tackle many societal challenges, such as declining water quality, air quality and food security. Their advantage over traditional hard infrastructure solutions is thought to be in their ability to provide "co-benefits", or additional benefits

Nature-based solutions (NBS) are defined as "*actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (IUCN, 2020) and are considered to be "*inspired by, supported by or copied from nature*" (European Union, 2015). Underpinning NBS is the protection and restoration of ecological infrastructure (EI), a term referring to "*the underlying framework of natural elements, ecosystems and functions and processes that are spatially and temporally connected to supply ecosystem services*" (Dominati, 2013). Neither NBS or EI have universal definitions – sometimes the terms are used interchangeably, and other times, EI is used as a more specific concept that falls under the NBS umbrella (Luedke, 2019). Here, we regard it as the latter. Much attention is currently focused on promoting and applying NBS in the urban context (Lafortezza *et al.*, 2018). However, the focus remains on the urban core while the peri-urban areas, that are

transition spaces often affected by expansion processes of the city, remain under-explored. Peri-urban areas may be originally large 'green' open spaces such as woodlands, farmlands and nature reserves in the urban periphery, and include 'blue' spaces like river, riversides & waterfronts. These have historically played important role in development and sustenance of urban centres, provision of water-related ecosystem services, particularly water supply, wastewater management and flood control. However, with urban expansion, as natural environments are increasingly replaced by 'built' environment, the resources contained within these peri-urban areas are increasingly under pressure. Erosion of natural environments leads to disruption of ecosystem services, causing water challenges regarding both quantity and quality. These challenges lead to critical water cycle gaps which affect the urban core as well as peripheries.

There is need to find sustainable solutions for these gaps as reflected by the 2030 Agenda for Sustainable Development and the SDG 6, ("*Ensure availability and sustainable management of water and sanitation for all*"). There is also a need to explore the potentials and appropriateness of NBS in the peri-urban. The importance of NBS is worded in Target 6.6 of the SDGs which states: "*By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes*". To support the achievement of SDG 6, the international project aimed to contribute to closing the water cycle gap in peri-urban areas by building shared knowledge on NBS based within and outside the European context.

There is a particular need to advance knowledge of how nature-based solutions for water, with a focus on the peri-urban, can be assessed on different sustainability parameters and now these nature-based solutions can be increasingly adopted within urban development practices. This project moves beyond the state of the art by taking a systemic perspective on nature-based solutions for water, with emphasis on complexity, uncertainty, resilience and adaptation for different peri-urban contexts. It focusses on the need to ensure the involvement of multiple stakeholders and combine multi- and transdisciplinary knowledge as key elements in the implementation and assessment of nature-based solutions as local responses with replicability potential, helping make progress from a sectoral policy towards a new urban management paradigm.

1.2 Project Aims

This report is part of a greater Water Joint Programming Initiative (JPI) research project (see **section 1.3**) and has four main aims. The South African team as part of the project, see **section 1.5**, worked collaboratively on these aims, but contributed specifically to six main sub-aims (blue text below). These aims are listed below, and products given in bold. The project website is **product 1** and is detailed in see **section 2.1**.

1 Review international experiences (*collaborative* – ***product 2***)
2 Establish a methodological framework (*collaborative* – ***product 3***)
3 Apply this methodological framework to the case studies
  3.1 Conduct an analysis of the South African case study sites
  3.2 Write case study briefs (**product 4**).
4 The creation of a common narrative
  4.1 Narrative report: Identify the main challenges for implementing nature-based solutions (e.g. ecological, socioeconomic, technological, political, legal, planning governance, and institutional dimensions); and reflect on the socio-political context that favours the implementation of nature-based solutions.
  4.2 Assist in the production of a policy brief (**product 5**)
  4.3 Write popular science publications for case study sites for the website (**product 6**).

4.4 Assist in the production of a Handbook for practitioners that can promote & inspire implementation of nature-based solutions in the peri-urban (**product 7**).

1.3 Project Context

The project formed part of a greater JPI Project. It aimed to **contribute to closing the water cycle gap** by exploring the potentials that nature-based solutions offer to address water management challenges in landscape areas that have been neglected because they lie in the transition zones between the urban and the rural, hereby referred to as peri-urban areas. The main objective was to exchange learning experiences among the partnership and promote the debate between science and society to increase awareness among practitioners and users on the application of nature-based solutions to manage water scarcity, pollution, and risks related to extreme hydrological events.

The JPI project included case study sites in South Africa, Norway, Sweden, Spain, Poland, India and Brazil at peri-urban areas where the project partners had established contacts. There are 4 project sub-objectives:

(1) Review of international experiences;
(2) Establish methodological framework to assess NBS;
(3) Apply the framework at each of the case study sites;
(4) Create a common narrative.

1.4 Structure of this Report

This report is structured as a series of products which were compiled as part of the South African team's involvement in an international consortium. Therefore, although this report is structured in a logical sequence: introduction, methods, results and conclusions, each section is also a standalone unit (although all references are compiled into a single section at the end, and supporting material is contained in the **Appendices**). The report starts with the introduction where it describes the scope of the study, its aims, the context and the international consortium, and the aim of this report.

The next section is the methods which is composed of four parts: (2.1) a detailed description of the study sites, (2.2) the NATWiP handbook which details the conceptual framework used in this study, (2.3) the case study interview schedules which were used to conduct the interviews, and (2.4) a global literature review which has been submitted for publication in a peer-reviewed journal.

The next section is results, and it is composed of three parts: (3.1) the narrative reports for the two South African case studies (one of which has been accepted for publication in a peer-reviewed journal), as well as workshop results on the global narrative, (3.2) the case study briefs for the two study sites, and (3.3) the photo stories for the South African case studies. In section 4, we conclude this study with some last thoughts, and then list recommendations in section 5. We include some information on project achievements in Appendix 6.

2. Methods

The NATure-based solutions for Water management In the Peri-urban (NATWiP) Project forms part of a greater international project, which aimed to develop a framework to assess the sustainability of nature-based solutions, and to apply this framework to nature-based solution case studies around the world, to make comparisons and to draw together common findings. For the South African part of this larger project, we selected two nature-based solution case studies: the Genius of SPACE project (Langrug, South Africa) and the Dwars River Alien Tree Clearing Project (Dwars River, South Africa). In this methods section we:

1. Describe these two case studies;
2. Introduce the NATWiP Handbook (Appendix 1), which describes the development of the framework and its application to the two South African case studies, and;
3. Describe our interview schedules (Appendix 2a&b) that were developed for these two case studies for the application of the NATWiP framework.

2.1 Site Description

2.1.1 Context: The Upper Berg Catchment and Case Study Overview

The two nature-based solutions case studies all occur within the Upper Berg catchment in the Western Cape of South Africa (**Figure 1**). The Berg River is approximately 285 km long from source to sea, with a basin area of approximately 9 000 km^2. Both locations fall within the jurisdiction of Stellenbosch Municipality. Mean Annual Precipitation ranges from high in the mountainous parts of the Upper Berg catchment (around 3500 mm/a) to low in the lower parts of the Berg catchment (as low as 60 mm/a) (DWAF, 2007). In terms of geology, the Upper Berg catchment is dominated by the sandstones and quartzites of the Cape Supergroup, mostly of the Peninsula Formation. The lower valleys have eroded through these to the basement Cape Granites, which dominate the lower catchment areas, resulting in gentle open valleys (DWAF, 2008). Soils of the Berg catchment are mainly highly leached, with low nutrients, shallow on the mountains with alluvium in the valley-bottoms.

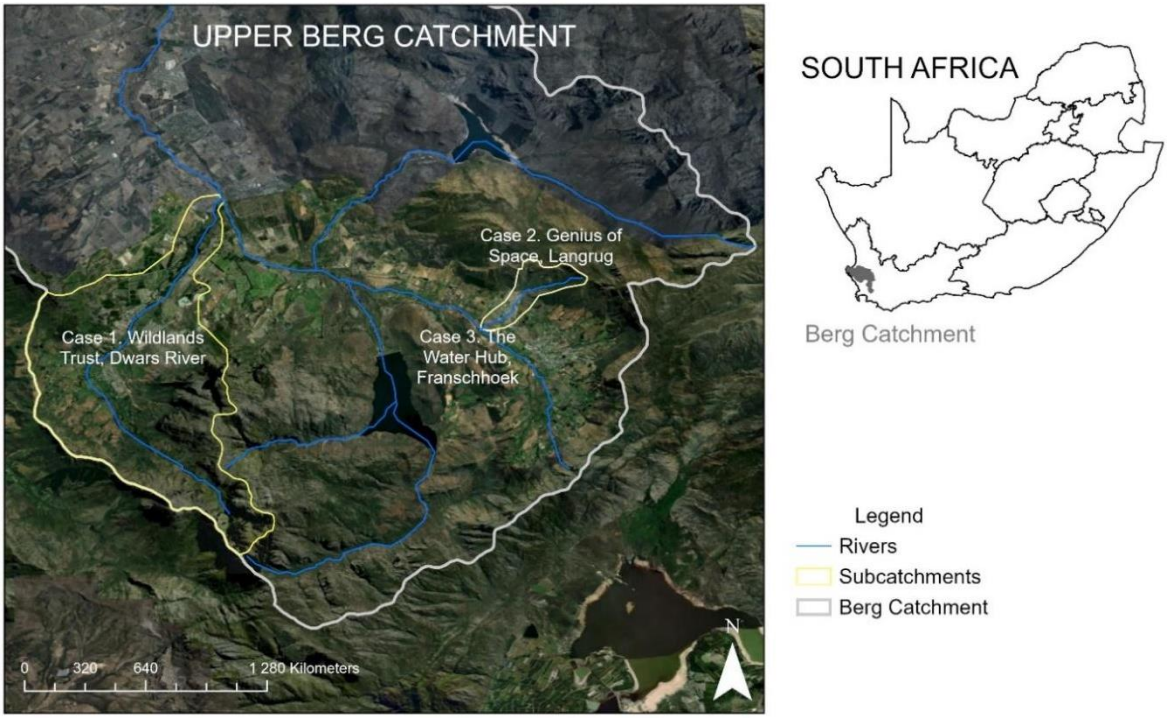


***Figure 1**. Map of the two case studies within the Berg Catchment, South Africa. The basemap is Google Earth imagery. A third case study is indicated, this is the Water Hub, which was subsequently not selected as no nature-based solution had yet been implemented at scale.*

About half of the land in the Upper Berg catchment is privately owned, mainly by farmers, with some luxury properties in the Upper Berg catchment, whereas the other half, especially mountainous areas, is managed by Cape Nature (**Figure 2**). There is a large portion of state-owned land above the Berg River Dam. The Berg Catchment is critically important for water supply, both to the City of Cape Town as well as for other sectors (especially agriculture and industry) (Forsyth *et al.*, 2016). The newly built Berg River Dam is an important part of the Western Cape Water Supply System. Downstream users of the Berg River include the towns of Paarl and Wellington, and various irrigation boards (Forsyth, Le Maitre and Lötter, 2016). The Upper Berg Major Irrigation Board, servicing farmers in the area, uses about 66 million m^3 each year, half extracted from the river, and the other half from farm dams (Forsyth *et al.*, 2016). The Upper Berg catchment is infested with invasive alien trees which are high water users, particularly pines, wattles and gums, but also alders, oaks and other weedy species (Keet, Robertson and Richardson, 2020). Parts of the catchment are rapidly developing (peri-urban) and, coupled with limited or dysfunctional wastewater treatment infrastructure, there are associated issues, such as sewage polluting the river.

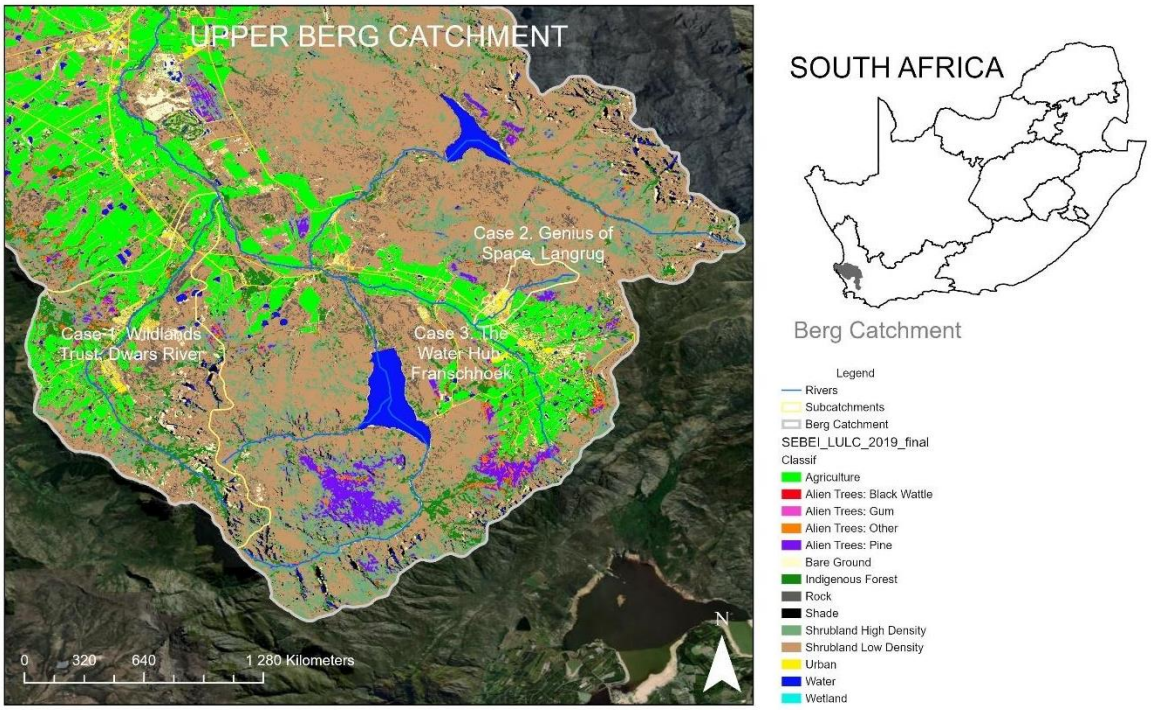


***Figure 2**. Land-use/land-cover in the immediate surrounds of the two case studies within the Berg Catchment, South Africa (Rebelo and Holden, 2020). A third case study is indicated, this is the Water Hub, which was subsequently not selected as no nature-based solution had yet been implemented at scale.*

2.1.2 Case study 1. The Wildlands Trust, Dwars River

Photo plate: Alien clearing in the riparian zone (left) and the biomass removed (right) in the Dwars River, South Africa.

Physical Context

The steep and rugged mountains surrounding the Dwars River are predominantly sandstone and quartzite, reaching up to over 1500 m above sea level (Simonsberg is at 1399 mamsl), whereas the wide valleys are highly arable (around 300 mamsl), dominated by decomposed granite and shale soils with good drainage (Forsyth *et al.*, 2016; Forsyth, Le Maitre and Lötter, 2016). The Dwars River (or Dwarsrivier) is a tributary of the Berg River. The geology of the Dwars river catchment is like that of the Upper Berg but also includes gritty sand, scree and alluvium covering granite of the Stellenbosch Pluton, with Cape Granite Suite in the valley. Soils are mainly dystrophic and/or mesotrophic. The mean annual precipitation of the catchment is around 1202 mm, most of this received in the winter. The difference in median precipitation between the driest month and the wettest month is 159 mm. The Dwarsrivier valley (63.87 km^2) is an important agricultural area, predominantly for viticulture and fruit farming, forming part of the Cape Winelands (**Figure 2**). Many of the farmers in the area are part of the Simonsberg Conservancy, which is the implementer for some of the alien clearing using Working for Water funding (NRM, DEA), and some landowners are WWF Champion Farmers. There are many small towns in the Dwarsrivier valley, including Pniel, Kylemore, Johannesdal, and Lanquedoc (Forsyth *et al.*, 2016; Forsyth, Le Maitre and Lötter, 2016).

One of the major issues in the Dwars River catchment is invasive alien trees, which are high water users. In the high-lying areas, pines are the major invasives (*Pinus pinaster* and *P. radiata*), in the middle slopes, especially in rivers, gums are dominant (e.g. *Eucalyptus camaldulensis*), and wattle's (e.g. *Acacia mearnsii*) are the major issue lower in the catchment, forming dense stands. Other riparian invaders include Oaks, Poplars and Elms (Forsyth *et al.*, 2016; Forsyth, Le Maitre and Lötter, 2016). Failing infrastructure (Pniel Wastewater Treatment Works) is also an issue, leading to sewage flowing into the rivers, as indicated by the high faecal coliforms and electrical conductivity entering the river through a dysfunctional sewage system (**Figure 3**, **Table 1**). This is a health threat to those using the river recreationally (often children) as well as agricultural produce that is irrigated by river water downstream. The river plays a strong buffering role for this sewage, probably largely through dilution effects (**Table 1**). Besides water security, invasive alien trees pose a major fire risk, through increased fuel loads. Fires are a natural part of this ecosystem, and are common in summer, between December and March (Forsyth *et al.*, 2016). These fires perpetuated the invasive alien tree problem through

stimulating the germination of large numbers of pine and wattle seedlings (Forsyth *et al.*, 2016; Forsyth, Le Maitre and Lötter, 2016).

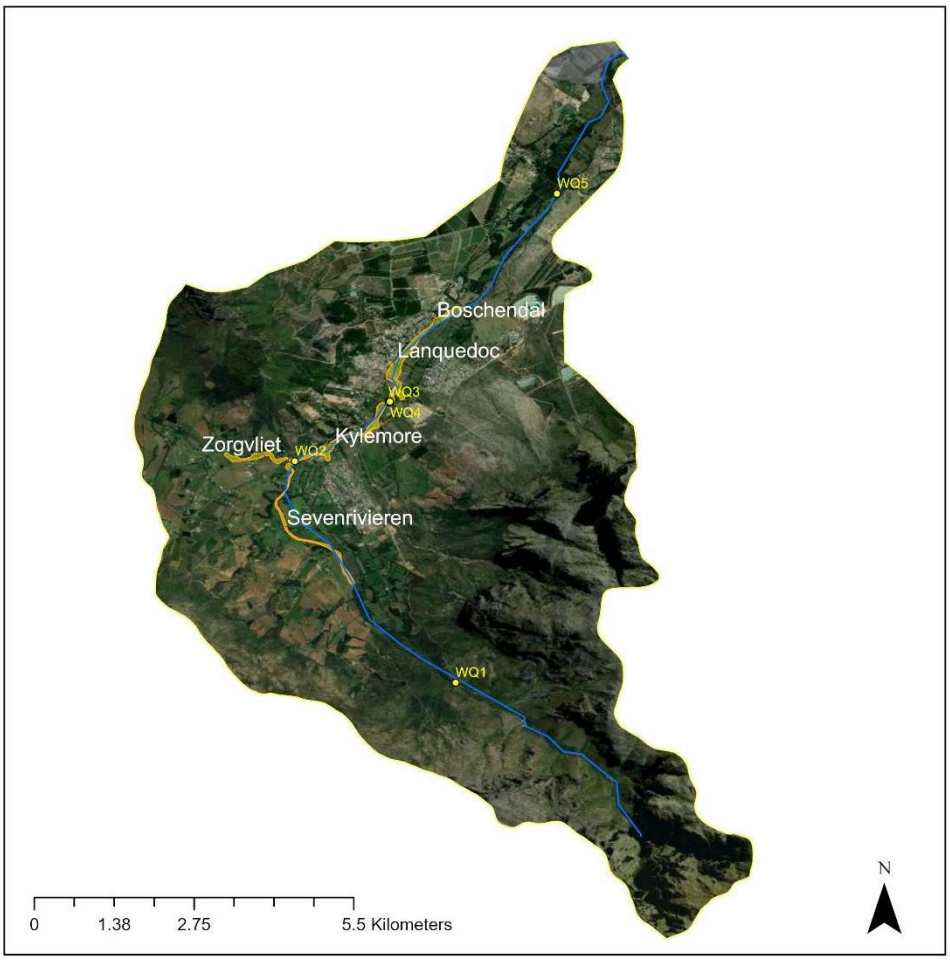


***Figure 3**. Rehabilitation sites for the Wildlands Trust along the Dwars River (orange polygons and labels in white) and water quality sampling locations in yellow. See **Figure 1** for context.*

***Table 1**. Water quality sampling in September 2018 by the Wildlands Trust along the Dwars River (see **Figure 3** for sampling locations). WQ2 (shaded) results show the influx of sewage.*

Site	Electrical Conductivity (mS/m)	NO3-N (mg/l)	COD (mg/l)	Suspended solids (mg/l)	Faecal Coliforms (CFU/100 ml)
WQ1	5	<0.36	8	0	2
WQ2	40	1.18	96	37	>2420
WQ3	11	1.28	8	0	109
WQ4	10	<0.36	7	0	38
WQ5	11	1.02	7	0	142

Socio-Economic Context

The Dwars River Valley has its recent roots in the colonisation of the Cape and has ties to slavery and oppression. As a result, the current socio-economic context is highly complex, with large inequalities between wealthy landowners (in some cases luxury properties) and people residing in the local towns (Van der Waal, 2005). The communities are affected by high crime levels and drug abuse (Methner

and Midgley, 2020). The valley may be classified as peri-urban given the fast paced, and highly contested, spatial transformation currently taking place (Van der Waal, 2005). New forms of land-use have led to conflict between farm workers and developers, especially where linked to heritage conservation (Van der Waal, 2005). In terms of population, in 2011 there were around 10 500 people living in Langrug and Groendal; and 5 390 on surrounding farms that intersect with the catchment (South African census 2011). In terms of the economic status of the catchment, there is a very high contrast, with rich farm owners adjacent to low-income communities. Much of the working population in the small towns are seasonal, working on surrounding farms (Methner and Midgley, 2020).

Governance Context

There are three levels of governance involved in the nature-based solutions (riparian rehabilitation) in the Dwarsriver, including national, some regional involvement, and to a lesser extent, local. National governance is primarily through providing funding for the riparian rehabilitation, funding is from National Treasury and channelled through the Department of Environment, Forestry and Fisheries (Midgley *et al.*, 2020). Non-Governmental Organisations administer the funds and coordinate the work, and in the Dwars river these include the Wildlands Trust, and the Simonsberg Conservancy. There is some regional government interest in the rehabilitation work along the Dwars River, primarily that of the Department of Environmental and Development Planning (Western Cape Government). In terms of local governance, the Stellenbosch Municipality is involved, mainly through their role in wastewater treatment and maintenance of local parks close to the river. There is some cross-pollination between tiers of government, for example the Department of Environment Affairs, Forestry and Fisheries specify catchment-based units of importance, and interventions are to be based on these specifications. National funding is in tandem with provincial planning, especially in the Natural Resource Management Programme; previously Working for Water, and all its affiliate groupings Working for Wetlands, Forests, etc.

Some of the major governance-related challenges include the lack of transdisciplinary engagement and operating in silos (Rebelo and Methner, 2019). Another major challenge includes the building of trust (Rebelo and Methner, 2019), within government tiers, departments and with communities, especially where there are diverse interests and agendas. How to sustain engagement and funding through various project cycles; how to mobilise the community (stakeholder engagement) and change patterns in decision-making are other major challenges that need to be addressed. Other stakeholders involved in the nature-based solutions in the Dwars River include community stakeholders (community committee, local residents, landowners), other non-governmental or non-profit organisations, recreational groups (e.g. Stellenbosch Trail Fund), other government departments (e.g. Department of Agriculture) and universities. The potential for socio-economic development and tourism opportunities is a leverage point that may bring this diverse group of stakeholders together to engage.

Nature-Based Solution & Implementation Context

As previously mentioned, there are several activities taking place within the Dwars River that may be considered nature-based solutions. For this case study we focused on the activities of the Wildlands Trust. The Wildlands Trust has been coordinating several riparian rehabilitation projects (the NBS) along the Dwars River since August 2018 (**Figure 3**). Funding is provided through the Natural Resource Management programme of the Department of Environment, Forestry and Fisheries. This riparian rehabilitation involves three approaches and takes place either on municipal or privately owned land.

Firstly, the clearing of invasive alien trees, shrubs and weeds from the riparian zone. The trees are cleared initially through logging operations, whereas subsequent follow-up clearing may involve foliar spray of herbicides, cutting and spraying of herbicides or hand-pulling, depending on the target invasive alien species. Secondly, there is active rehabilitation of the riparian zone, through the planting of tree seedlings. Thirdly, there is an attempt to engage the community through creating employment opportunities in the rehabilitation programme, as well as a recycling programme, aimed to keep the river clean, in exchange for bicycles. This project takes a socio-ecological systems approach and aims to both improve hydrological flows (increase water availability), improve water quality as well as engage the community (Adams, Whitfield and Van Niekerk, 2020). The scale of the implementation is relatively small, and there is a gap in South Africa in understanding how to upscale or finance these nature-based solutions at scale (Midgley *et al.*, 2020). Therefore the benefits of these interventions are anticipated to be mainly local, however any benefits in terms of augmented water supply or quality, would be beneficial to downstream farmers who rely on the Berg River for irrigation.

Research Objective

The aim of this case study is to evaluate the results of the Wildlands Trust invasive alien clearing and riparian rehabilitation of the Dwars River as a nature-based solution that aims to increase water quantity downstream. The study explored results in terms of all three dimensions of sustainability, namely, social, economic and environmental. One honours student from Stellenbosch University undertook a research project in 2021 to assess this nature-based solution.

In addition to this assessment of riparian rehabilitation of the Dwars River as a nature-based solution, there is a need to establish realistic goals for the active restoration of the Dwars River post rehabilitation (clearing of invasive alien trees). This is important to establish a reference condition, an understanding of which key native species would have originally defined different communities in the Dwars River. The aim of this is to establish which key species assemblages/communities should be present and what focal species should be used as restoration foci. This research was undertaken as part of an honours research project (Du Plessis, 2020).

2.1.3 Case study 2. The Genius of SPACE Project, Langrug

Photo plate: The informal community of Langrug (left) and some of the associated issues of recent immigration and infrastructure not keeping pace with demand (right), Franschhoek, South Africa.

Physical Context

The Stiebeuel River runs through the informal settlement of Langrug, draining a small subcatchment of approximately 4.37 km^2 (**Figure 4**) before entering the Berg River. The water of the Stiebeuel River is heavily polluted by sewage, litter, and domestic wastewater (Cameron, 2018). This is largely due to dysfunctional or inadequate drainage systems in Langrug, but also the low-cost housing area in Groendal, as well as agricultural effluent (Cameron, 2018). Therefore, there are significantly high loads of organic pollution and nutrients in the water which has a severely negative impact on water quality and therefore habitat integrity and species diversity of the river (Cameron, 2018). It also has severe implications for human health, especially for incidence of diarrhoea and pneumonia in children who play in the streets and areas contaminated by wastewater, who do not adopt sufficient hygiene practises (Olsson, 2017).

In terms of local geography, the informal settlement is situated on a mountain slope near the town of Franschhoek. The geology is predominantly composed of sandstones and quartzites of the Cape Supergroup, with alluvium in the valley-bottoms (DWAF, 2008), with Glenrosa and/or Mispah soil forms. The highest elevation is around 1221 mamsl, with the township situated at about 260-300 mamsl. The climate in Franschhoek is warm and temperate (average temperature of 16.4°C, with a minimum of 5.6°C and maximum of 28.4°C). The area experiences winter rainfall, with mean annual precipitation of around 903 mm. The difference in median precipitation between the driest month and the wettest month is 133 mm

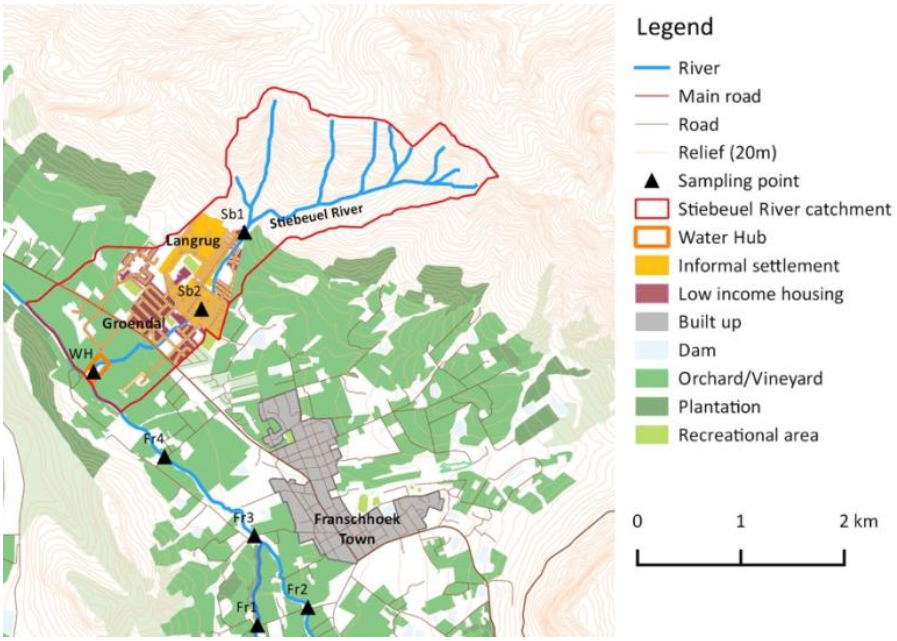


***Figure 4**. The Stiebeuel River at catchment, Franschhoek* (from Cameron, 2018).

Socio-Economic Context

The community of Langrug formed illegally on government land in the 1980s, mainly as a haven for job-seekers from the Eastern Cape looking for opportunities in the wine industry (factories or farming) (Olsson, 2017; Wolfaardt, 2017). Though the settlement was initially illegal, Stellenbosch Municipality provided basic community sanitation including toilets and taps (communal flush toilets), while others rely on surrounding vegetation. Due to vandalism, not all public ablution facilities are functional. In 2011, there were no individual toilets, 91 community toilet blocks (83 functional; 49 people/toilet); 57 water taps (45 functional; ~72 people per tap) (GGLN, 2013). Therefore greywater management, solid waste management and stormwater drainage are all a major concern in this informal settlement, like many others in South Africa (Armitage *et al.*, 2007). Research from 2007 found that Langrug lacked community structures that can facilitate 'self-help' solutions to greywater management (Armitage *et al.*, 2007). Though research shows that stormwater and sanitation cannot be separated from greywater management, residents appeared less concerned about greywater as a problem compared to other more pressing concerns, such as crime levels (Armitage *et al.*, 2007).

In 2012 the population of greater Langrug (including Groendal) was estimated at 13 000 inhabitants, with 10% of them being children under the age of five years old (Olsson, 2017). Langrug itself (composed of suburbs: Zwelitsha, Nkanini and Mandela Park) was estimated at between 16-17 years old, all homes are shacks, with about 4088 inhabitants, with 41% female-headed households (Stellenbosch Municipality, 2011). Most of these people have recently moved from the Eastern Cape (72%) (ISN, 2011). The economic status of this community is 'very low income' and despite poor water and sanitation services, most households have electricity meters in their homes, while the remaining population rely on paraffin, gas and petroleum. The working population comprises mostly seasonal workers from surrounding farms. The community has experienced flooding disasters (Jiusto and Kenney, 2016) and is affected by crime and drug abuse.

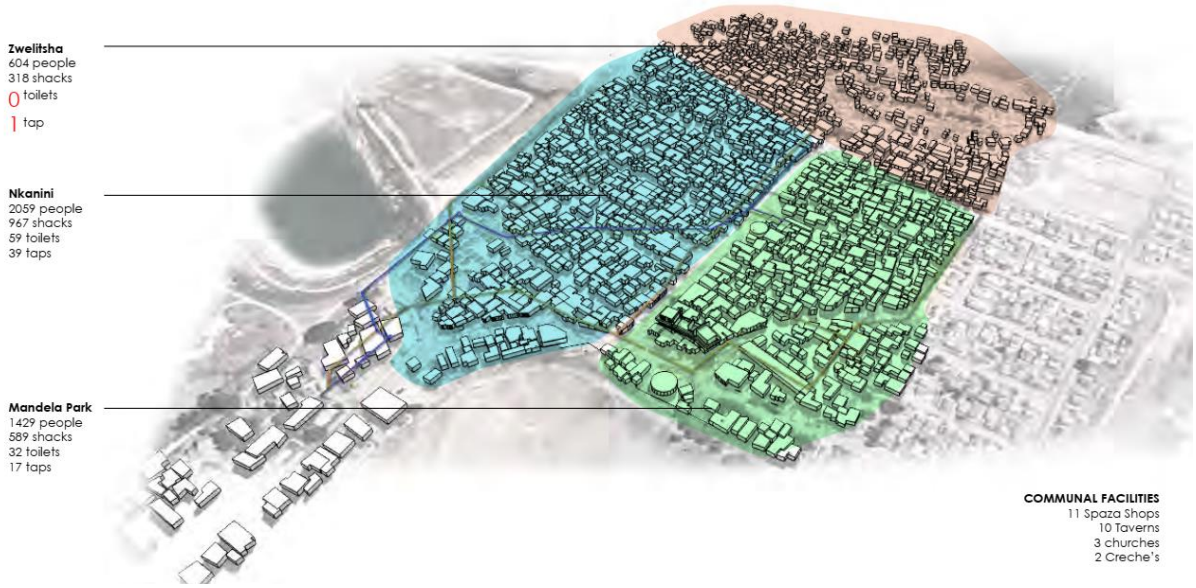


Photo plate: The informal community of Langrug, divided into three suburbs: Zwelitsha, Nkanini and Mandela Park.

Governance Context

Both local and regional governments have been involved in the Genius of SPACE Project; the Stellenbosch Municipality (local government) and the Department of Environmental and Development Planning (regional – Western Cape Government). In the community, a committee has been established to engage with these stakeholders, called: 'the Langrug Community Projects Committee'. There is a history of governance challenges in this municipality, related to ad hoc, top-down approaches to water-related service provision (Lande and Hendler, 2018). In 2012 a community-led approach was initiated, guided by the 1988 White Paper on Local Government (which includes provision of sustainable services through partnerships between local government, community-based organizations and non-governmental organizations). The partnership consisted of the Stellenbosch Municipality (Informal Settlement Management department; local government) and the Community Organisation Resource Centre (CORC) on behalf of the South African Shack/Slum Dwellers International Alliance. The Langrug Community Projects Committee (LCPC) were the initial intermediary, and the assumption was that community leadership groups would be mobilised and take over the process, however weak community structures meant that this did not happen. A range of projects were initiated, and the partnership then expanded to include the Worcester Polytechnic Institute and University of Cape Town; and the Mandela Park WaSH facility (Muniz, 2013) was conceptualised and completed in 2013 and in 2014 an Innovation Centre in the upper section of Langrug began, motivated by lack of sanitation facilities.

In 2015 the partnership MOU ended. Power relations, community leadership divisions and community ownership issues arose, and the WaSH facility & Innovation Centre were vandalised and misused and eventually demolished by the community. Another issue cited is that benefits of projects did not necessarily filter down to household level. In 2015 a new initiative started – the Genius of SPACE project (the focus of this case study) – a collaboration between BiomimicrySA & Informal South (organizations comprising scientists, engineers, architects and innovators that seek designs that use nature-based solutions) and the Western Cape Government's 110% Green Initiative; the Langrug Community Projects Committee was established as the community driver of the project (elected

through a general meeting, consisting of community leaders, ward committee members, etc.). Coordination challenges are well-summarised in the following extract: "*Existing local realities of hierarchy, gatekeeping, and powerbrokers have worked against some of the aims of the alliance, which include the building of social capacity*" (Lande and Hendler, 2018). Some of the major challenges related to governance include how to change patterns in decision-making; how to build trust, how to sustain engagement and funding through various project cycles and how to mobilise the community (Armitage *et al.*, 2007; Wolfaardt, 2017; Tàbara *et al.*, 2020). Other research argues that this project has been far from transformative, because it relies on the free or cheap labour of unemployed women for successful implementation (Meiring, 2017). In terms of the benefits, only well-connected women are able to access the resources and opportunities provided by community benefactors, excluding many others (Meiring, 2017).

Nature-Based Solution & Implementation Context

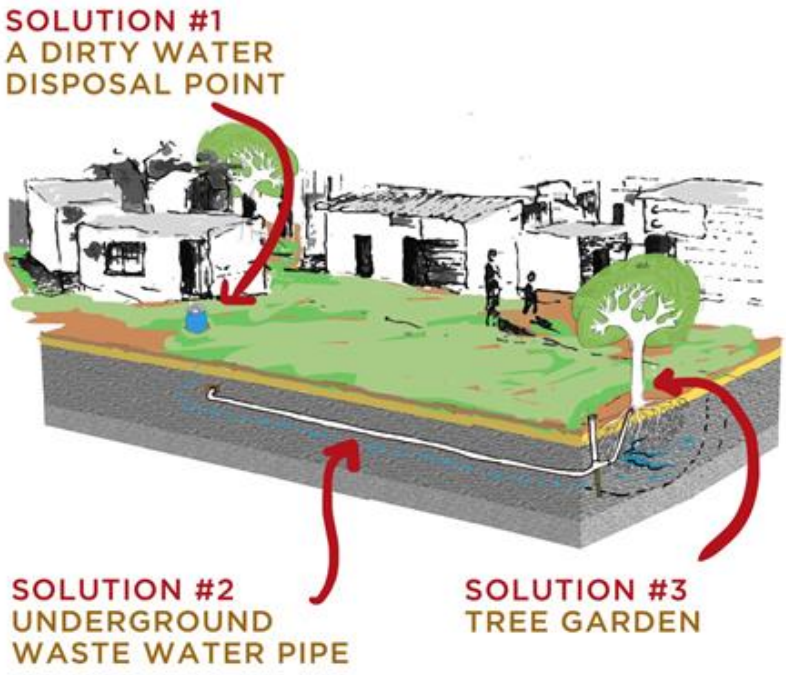


Photo plate: The three solutions proposed by the Genius of SPACE Langrug Community Project, South Africa. Greywater disposal points situated strategically throughout the community allow safe disposal of greywater, which is directed through underground pipes to a tree garden site and an associated micro-wetland (not shown here), where soil and plant filtration services theoretically clean the water and allow conversion into a productive use. Source: Genius of Space Information Brochure

The Genius of SPACE Langrug Community Project proposed a systems-approach to water and waste issues, using methodology that applies nature-based principles to solve water-related challenges. The Genius of SPACE project implemented three solutions in a pilot project: (1) 27 greywater disposal points to manage greywater run-off and the collection and separation of household solid waste in wheelie bins (compostables, recyclables, non-recyclables), (2) underground wastewater pipes to reduce local flood risk and stormwater management (improved road surface with permeable paving,

grading and pavement construction) and (3) 15 tree gardens (DEADP, 2018). Eleven fulltime Langrug locals were employed on the Genius of SPACE Project (Wolfaardt, 2017). This intervention was implemented by BiomimicrySA & Informal South (organizations comprising scientists, engineers, architects and innovators that seek designs that use nature-based solutions) and the Western Cape Government's 110% Green Initiative), however its success needs to be evaluated, building on the research already completed. The benefits of this nature-based solution, i.e. the use of soil and plant filtration to reduce the impact of greywater disposal, are intended to be local (for the community) by reducing flood and disease risk, and improving the community, but also downstream (improved water quality). The Stiebeuel River flows into the Berg River, which is a critical water supply for farmers downstream.

It should be emphasized that the Langrug community is a site of extensive research, with a focus on participatory action methods which emphasise "*participation, collaboration and consensual decision-making with the goal of ensuring long term sustainability of social and technological interventions*" (Carden *et al.*, 2008). However, as suggested by the challenges listed in the section on 'governance context', despite its grass-roots approach, many of the Genius of SPACE initiatives have not continued (DEADP, 2018). Even in 2008, certain risk factors in the community for these types of projects were identified, including: uncertainty about tenure/ownership undermining willingness of inhabitants to take initiative, as well as general unwillingness to take responsibility for service delivery believed to be the municipality's responsibility (Carden *et al.*, 2008).

Photo plate: Domestic greywater treatment: Greywater flows from the disposal points through pipes to a tree garden then into "micro-wetlands" to undergo a second round of filtration and cleaning. Genius of SPACE, Langrug Community.

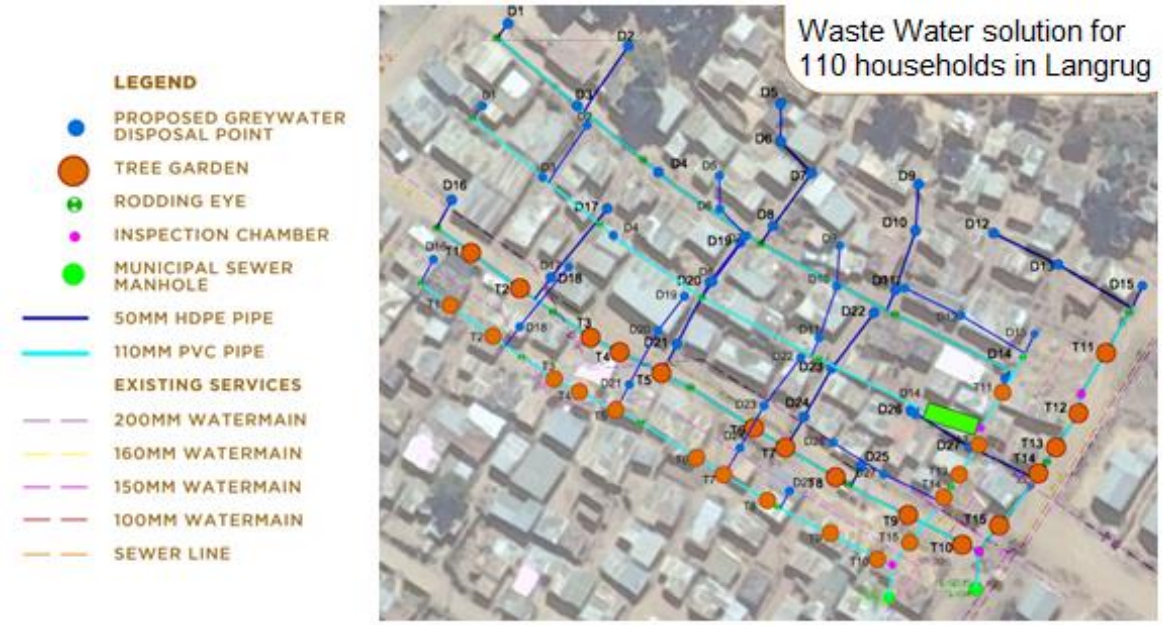


Photo plate: Wastewater solution piloted for 110 households in Langrug Community, including 27 disposal points, 15 tree gardens (source: Langrug Community Project News, May 2016)

Research Objective

The aim of this case study was to evaluate the results of the Genius of SPACE project as a nature-based solution that aims to reduce local and downstream pollution impacts in the informal peri-urban area of Langrug, especially as relates to the components listed as completed in the final project implementation report (DEADP, 2018). The study explored results in terms of all the three dimensions of sustainability, namely, social, economic and environmental. One honours student from Stellenbosch University undertook a research project in 2021 to assess this nature-based solution.

Rather than imposing another "rigid external development model" onto Langrug, the Genius of SPACE project involved local community members in a slow, adaptive process of cooperation, designing solutions that the residents of Langrug want (Hermanus and Campbell, 2017). While not all issues have been solved, it is said that the Genius of SPACE project has laid the foundations to do so, "*assuming the continuation of investment and incremental improvements over time*" (Hermanus and Campbell, 2017). We investigated whether this project is sustainable and successful, given this novel approach.

2.2 The NATWiP Handbook

The handbook describes the method developed by the international NATWiP team to assess the sustainability of nature-based solutions. The method was developed and led by Brazilian partners in collaboration with the NATWiP team and was subsequently applied to the different international case studies. The South African team was involved in the compilation of this output that is aimed to be a practical guideline. The full handbook is provided as Appendix 1, but briefly described in this section.

The handbook provides guidance on the holistic consideration of nature-based solutions to support water sustainability in peri-urban areas.

The reader is presented with an innovative, holistic, and operational framework that has been developed through transdisciplinary processes. The framework considers all three phases of nature-based solutions, the first being the socio-spatial context assessment (research and planning phase), the second is the implementation processes (implementation phase) and the third is the evaluation of results, including long-term results, unintended consequences, and co-benefits (monitoring and evaluation phase).

For each of these three phases, three sustainability dimensions are considered: environmental, social, and economic. This means that even though the NATWiP Framework focusses primarily on peri-urban areas and water-related nature-based solutions, it can be applied more broadly. The framework includes a set of indicators for each dimension within each of the three phases that can be adapted to local contexts. Users may consider applying the framework as a tool to evaluate ongoing projects and to guide new ones, across different countries, landscapes, and contexts. The NATWIP Framework template and the South African Indicator spreadsheet can be found in **Appendices 3a** and **3b**.

The handbook provides a brief overview of concepts in Chapter 1, with a description in Chapter 2 of the methodological framework. Chapter 3 offers step-by-step instructions on how to apply the NATWiP Framework. Chapter 4 illustrates how to apply this framework, through a series of case studies gathered from across the world. The case studies are at various stages of planning or implementation. Finally, in Chapter 5 main lessons learnt from the case studies are drawn together and seven principles of best practice for nature-based solutions – aiming to be sustainable – are proposed. The handbook concludes with Chapter 6.

While this handbook does not provide technical guidelines for nature-based solutions, it is intended for anyone. Practitioners or researchers who want to consider a more holistic framing of nature-based solutions may use this framework for designing, implementing, or monitoring and evaluation purposes.

The over-arching aim of the NATWiP Framework is to ensure that sustainable development goals are explicitly considered in water-related, nature-based solutions projects, in order to catalyse the United Nations *2030 Agenda for Sustainable Development*.

2.2.1 Background – development of the handbook

In 2020 a review was published by Ramírez-Agudelo *et al.* (team members responsible for Work Package 1) of the current knowledge on the implementation of nature-based solutions for peri-urban area water management. It includes 35 international experiences that identify barriers and lessons learnt when implementing different types of nature-based solutions.

The different elements of governance (for example policy instruments, organizations and roles) were shown to be vital for linking the environmental, social and economic dimensions in nature-based solutions. As a result, a benchmark is provided that deals with the water cycle gap and water management in these areas.

Findings in this review served as the conceptual basis to examine the definition of nature-based solutions and its development as a policy concept. It also identifies details on the implementation of nature-based solutions for water management, such as the practical applications, tools and assessments. This helped form the basis for the outline and development of the NATWiP Framework

In the literature described by Ramírez-Agudelo *et al.*, the nature-based solutions definition has been widely examined. The characterisation of nature-based solutions as an 'umbrella' concept relates to its comprehensive approach to achieving systemic interventions that deliver multiple benefits to multiple stakeholders in a resource-efficient manner.

The 2020 review explored the keywords used in nature-based solutions literature to examine cross-cutting topics. The literature highlights the process of nature-based solutions implementation as that of dynamic change, being shaped by its nature of problem-solving, as well as being highly context-specific. The review also found that nature-based solutions – regardless of their type, scale, or location – have the potential to provide multiple benefits and service.

Several success factors and barriers that could favour or obstruct, respectively, the implementation of nature-based solutions were highlighted from the literature by Ramírez-Agudelo *et al.* (2020):

Success factors:

1. **Good communication:**
   This is a critical tool among various stakeholders and organisations (public authorities, private actors and industry, academia and research, civil society and community-based collectives, etc.).
2. **Consideration of different roles and responsibilities**
   Recognition of the fact that nature-based solutions implementation involves different stakeholders with different roles, at multiple levels of decision-making and territorial scales (from local to national, or regional).
3. **Monitoring Change**
   This is highlighted as being important, considering the different sectors that may be associated (e.g. water, transport, urban planning, energy, food, sports, health, cultural, etc.). This is where the NATWiP Framework is able to add significant value.

Barriers:

1. **Complexity**
   The complexity of a comprehensive approach to nature-based solutions may lead to technical, institutional, economic and social uncertainties.
2. **Technological/Infrastructural Limitations**
   There is often a lack of technological capacity or a lack of necessary infrastructure when it comes to nature-based solutions.
3. **Institutional Capacity**
   Even if public authorities are playing a vital role in the promotion of a nature-based solutions, by funding it and promoting research and policies, there may be limitations to institutional capacity. These may have economic repercussions.
4. **Alternative business models**
   Alternative business models are sometimes weak or unconvincing. This could restrict strategic partnerships and support for nature-based solutions by private actors.
5. **Involvement of diverse actors**
   The interaction between a diverse group of actors involved in nature-based solutions could promote greater advances in actionable knowledge, wider perspectives, and constructive discussions.

The NATWiP Framework builds on current knowledge incorporates various dimensions of sustainability (e.g. environment, society and economics) to provide a state-of-the-art tool for implementers and researchers.

Lima *et al.* (2022) propose two forms of the framework: one is conceptual (**Figure 5**) and the other is operational (**Figure 6**). Looking first at the Conceptual Framework (**Figure 5**), it is represented by a simple, visual scheme. The aim of the scheme is to summarise the main concepts and processes of the operational framework. The different phases of the planning cycle provide a logical flow to the Conceptual Framework. Concepts of 'co-benefits' and 'well-being' are highlighted as outcomes of the nature-based solution, which might be identified in the medium or long term.

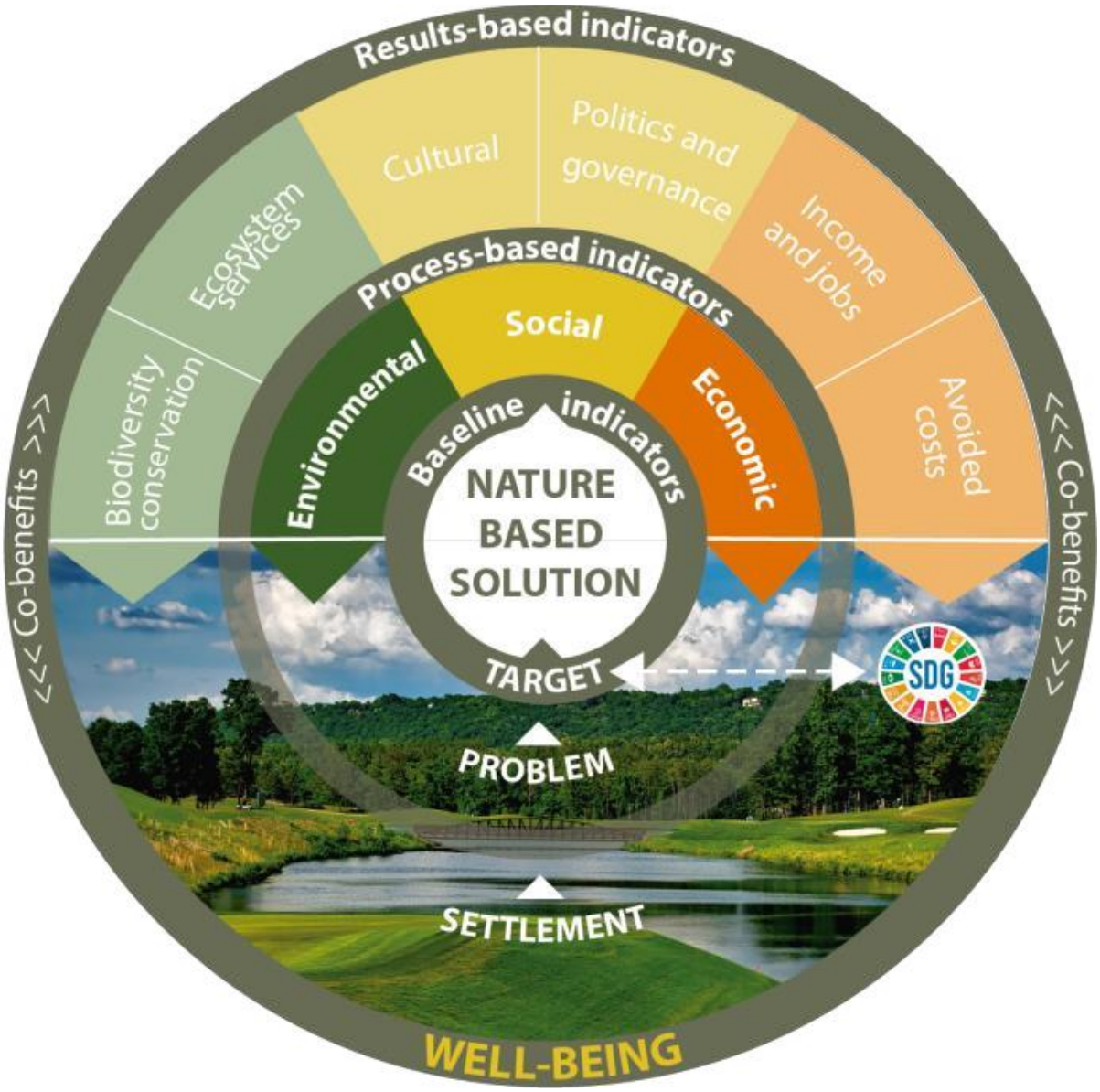


***Figure 5**. The NATWiP nature-based solution Conceptual Framework (Lima et al., 2022). "SDG" indicates 'sustainable development goals'.*

When designing a nature-based solution the departure point is 'well-being' and the specific setting and problem need to be identified and defined. Once this has been done, the target can be defined and the nature-based solution can be designed.

Baseline indicators can then be developed and assessed to understand the context and to have baseline conditions to compare results to. These indicators correspond to the three dimensions of sustainability: environmental, social and economic.

When the nature-based solution is implemented, process-based indicators can be developed and assessed. These assess how the process is unfolding – also in terms of the three dimensions of sustainability.

Lastly, when the nature-based solution has been implemented, result indicators can be developed and assessed. This can be done either after the project, or as part of continuous monitoring and evaluation. The results may also produce co-benefits. This framework allows for the capturing of these co-benefits and other indicators from each of the three dimensions of sustainability.

On the other hand, the Operational Framework (**Figure 6**) is a complete plan that can be followed step-by-step and applied to design and implement a nature-based solution. It may be applied either at the start of a project or it may be used to monitor a project after implementation.

There are three main phases to the Operational Framework (each phase corresponding to one of the boxes in **Figure 6**):

1. The spatial context assessment
2. The nature-based solution implementation process
3. The results

These three phases are organised in a logical flow following time (indicated by 'Temporal scale'). They are also related to different planning cycle phases (top, bold arrows in **Figure 6**), common to every nature-based solution project.

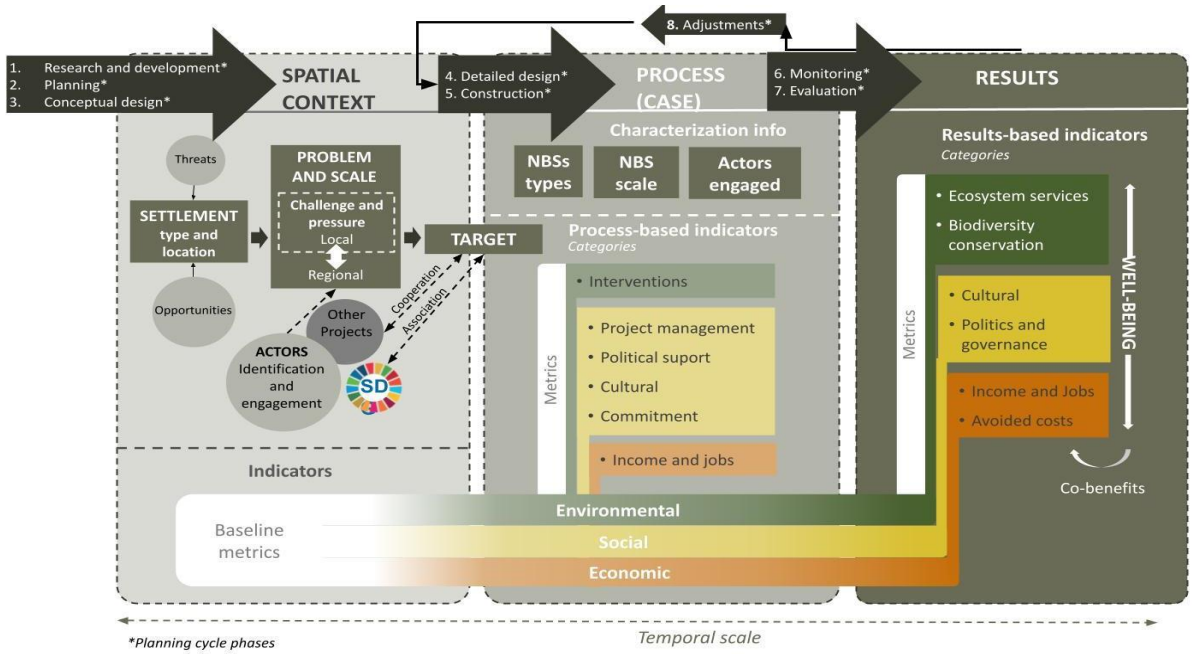


***Figure 6**. The NATWiP nature-based solution Operational Framework (Lima et al., 2022). 'SD' Refers to sustainable development goals.*

The first phase of the Operational Framework (box 1, **Figure 6)** is the socio-spatial context with elements that should be identified and assessed to implement or monitor a nature-based solution

project successfully. The nature-based solution has to be designed according to this context, the type of settlement and its location, with the aim of solving a well-identified problem. Consideration has to be given to the threats and opportunities associated with it, as well as to the local and regional stakeholders involved.

In this initial phase it is also important to establish the project targets that can be associated with sustainable development goals (or other projects in the region). Consider how these goals influence the design of actions, including definitions of the desired impacts, as well as specific nature-based solutions. Here the importance of defining the baseline indicators that make it possible to quantify the impact of the project activities is highlighted. The indicators allow a before-and-after snapshot of the interventions.

The second phase of the Operational Framework (box 2, **Figure 6**) details the process of characterisation and design of the actions. These include defining the nature-based solution types and scale (consistent with the problem and scale identified in box 1) and the stakeholders engaged in the implementation of the nature-based solution.

Aiming to support evaluation and monitoring, the NATWiP Framework indicates process-based indicators that are divided into categories, associated with three main sustainable dimensions (environmental, social and economic).

In the third and final phase (box 3, **Figure 6**) result-based indicators are shown that are associated with the sustainability dimensions identified in the previous phase. These should help assess whether the planned actions resulted in the desired impacts, generating co-benefits and well-being to society – locally or regionally. If not, the framework assists in identifying which adjustments should be made to improve the process and the project interventions.

The indicators were categorised as being either process-based or results-based, according to the Theory of Change approach. Processed-based indicators provide information on implementation of nature-based solutions. Results-based indicators measure how effective nature-based solutions are. However, indicators should be selected case by case, depending on the social context, targets and defined goal(s). That is why the NATWiP Framework proposes broad categories and indicators, which are mainly based on analyses from the NATWIP Project case studies.

The NATWiP Framework has a flexible structure that can be adjusted to relevant projects (and their unique context), as well as to each of the three sustainability dimensions (environmental, social, economic) and implementation phases (research and planning; implementation; monitoring and evaluation). Likewise, all information required to apply the framework can be collected through various methods, such as questionnaires or mapping or monitoring of the nature-based solution project.

The framework structure proposes a logical flow of information to guide projects before, during and after implementation. At the start of a project (e.g. during the research, planning and conceptual phase), the framework can be used as a guide to highlight the main information that must be considered, acquired and accounted for *before* nature-based solutions activities are implemented.

If a project has started and the nature-based solution is already implemented, the framework can be used in one of two ways. It can either be used to organize data and evaluate processes and results to identify necessary adjustments; or it can be used to quantify results and benefits. To assist practitioners in applying the framework in a more organic way, a simple step-by-step scheme is proposed (**Figure 7; for details see Appendix 1**).

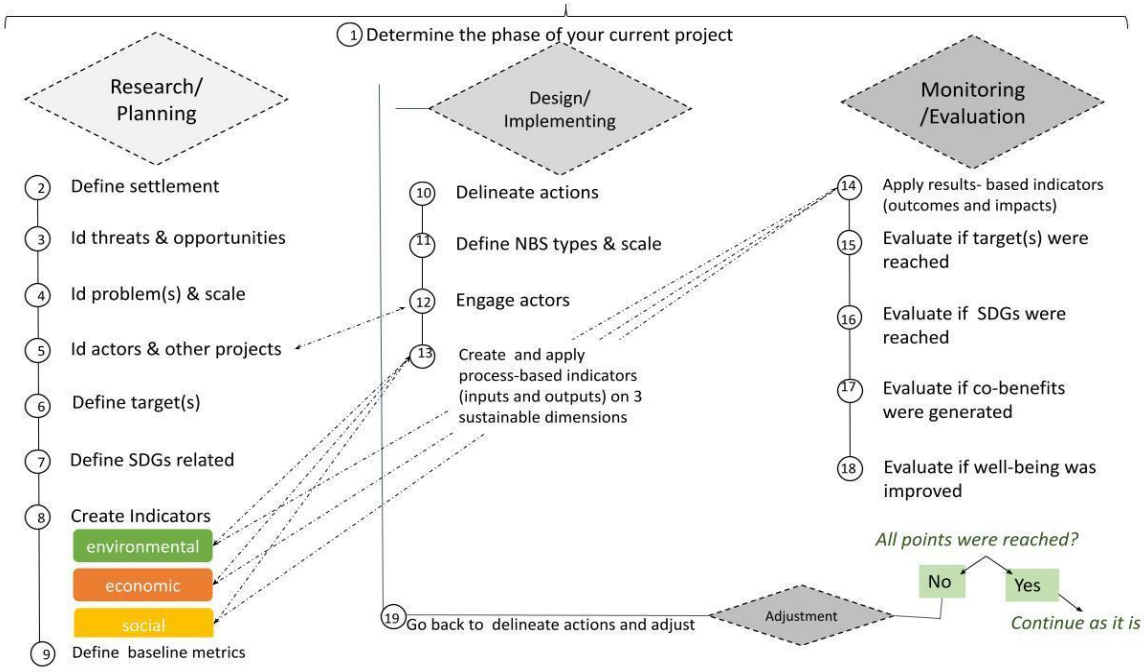


***Figure 7**. Step-by-step guide to apply the NATWiP Framework to any nature-based solutions case study, whether in the research and planning phase, the implementation phase or the monitoring and evaluation phase. Numbers indicates process steps. "NbS" implies 'nature-based solutions'; "ID" refers to 'identify'; "SDG" indicates sustainable development goals'.*

The handbook demonstrates how the NATWiP Framework was applied to nine case studies across the world (illustrated in **Figure 8**) as part of the NATWiP Project. Each study considered different nature-based solution types in specific phases of nature-based solution projects: research and planning (Phase 1); implementation (Phase 2); or, monitoring and evaluation (Phase 3).

For an example of the NATWiP Framework see **Appendix 3a**. Examples of indicators for a specific nature-based solution may be found **Appendix 3b**.

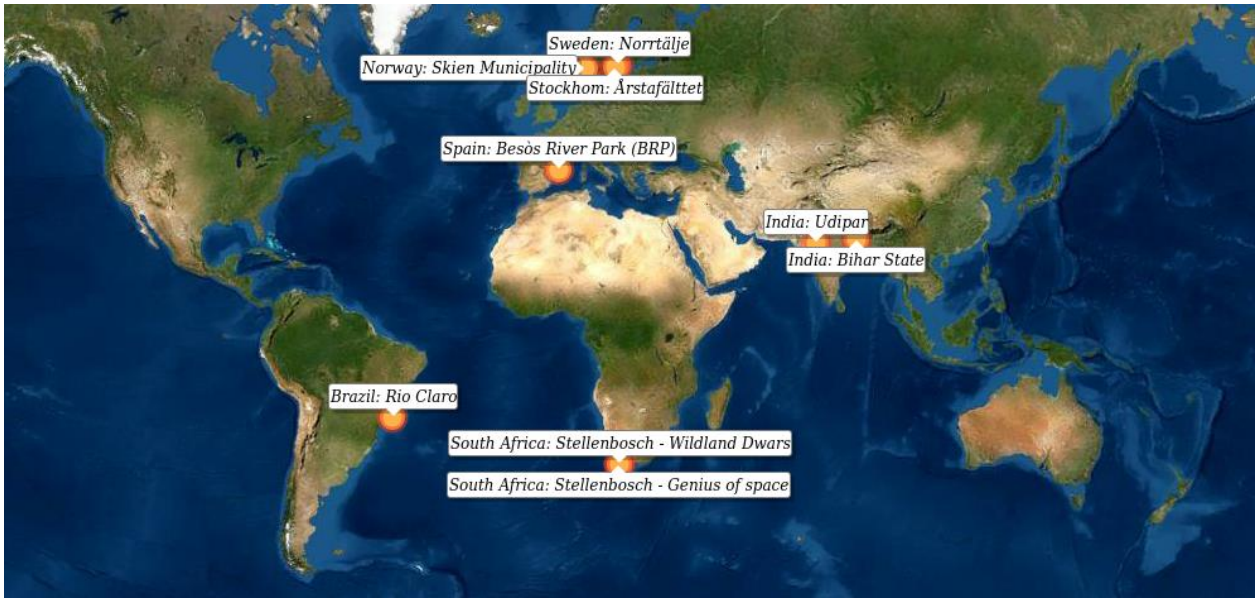


***Figure 8**. The nine nature-based solutions case studies from the NATWiP Project are spread across the world, with five in the Global South and four in the Global North. The map can be accessed and viewed with many different and relevant layers here: http://miljo.ngi.no/natwip/.*

The handbook describes lessons learnt from the case studies. A reflection is then provided on the opportunities and constraints highlighted within the unique context of each case study, especially those that overlap between various case studies. Finally, we link lessons learnt to best practices that may guide handbook users to pursue successful nature-based solutions interventions.

The nature-based solutions case studies described are all rich and diverse and hold educational value. Some of the lessons are common to several case studies and some are unique to a particular site. What is clear is that the context of a case study is very important when considering best practice. Best practice in one geographical area may not hold relevance to another geographical area. Likewise, best practice for one type of nature-based solution, may not be applicable to another. Thus, while the intention is that the NATWiP Handbook describes main lessons learnt, these are still quite broad and general, given the complexity and diversity of the case studies.

The overarching message of the handbook is that nature-based solutions provide a valuable solution to critical water-related challenges in peri-urban areas. The NATWiP Framework, in particular, is a state-of-the-art tool because it may be used to plan or design a nature-based solution, to implement it, or to monitor and evaluate it. All the while the three dimensions of sustainability (environment, social and economic) are considered.

The NATWiP Handbook describes the framework, explains how to apply it and showcases nine international case studies – in various phases of implementation – that have applied this framework in diverse ways. The case studies demonstrate lessons learnt, opportunities and constraints for nature-based solutions and some tips for best practice.

A crucial insight is that nature-based solutions often reap multiple co-benefits alongside primary (or key) benefits, but often over long timeframes. This is often at odds with society's desire for rapid change or immediate solutions. Evidently, there is a need to sensitively manage the public's (representing the full spectrum of potential stakeholders) diverse expectations. This requires careful communication – perhaps through strategic channels, such as public relations and educational campaigns.

These temporal scales need to be considered when deliberating nature-based solutions. For example, compared to grey infrastructure, which offers quick solutions, nature-based solutions rewards may generally take longer to be realised. But this means they often also last longer, yielding multiple co-benefits far into the future.

Against a backdrop of anthropogenic climate change and the need for nations to adapt and mitigate against it, nature-based solutions offer an attractive and sensible way forward. If they are to be truly sustainable, however, careful thought needs to go into their design, implementation and monitoring and evaluation. The purpose behind the NATWiP Handbook is that it contributes to achieving more sustainable nature-based solutions for water management in peri-urban areas, and elsewhere, in the future.

2.3 NATWiP South Africa case study interview schedules

Introduction

To apply the methodological framework designed by the NATWiP project team to the South African case studies, the framework needed to be converted into an interview schedule for both implementers and community members (**Appendix 2a, 2b**). This resulted in two separate interview schedules for each case study. To assess the context, process, and results of the nature-based solutions in the two South African case studies (in line with the framework), projects were assessed in relation to the ecological, social and economic dimensions of sustainability. These interviews received ethics approval from Stellenbosch University: HSRC Research Ethics Committee (REC) (ethical clearance number: REC:SBE 13114).

Implementers were interviewed (target: 5-10 individuals from different organisations) between January and March 2021 via a virtual platform such as Zoom, using a snowball approach starting with recommendations of the main nature-based solution project implementers at each case study site. The interviews were conducted by the South African NATWiP team in English and recorded. The recordings were transcribed and then analysed.

Community members were approached via community leaders, also on recommendation of the main nature-based solution project implementers at each case study site. We targeted 20 individuals from each community and tried to cover a diversity of people (age, gender, race, land ownership type) where possible. A physical meeting was arranged, and costs covered to offset any travelling costs or compensate for time. To minimise travel costs, community members were met at a safe, central location for interviews, at a library community hall and school hall in the Dwars River, and at a library seminar room in Langrug. Covid protocols were always observed. Interviews were conducted in Afrikaans and isiXhosa, and recorded, transcribed, and translated into English, and then analysed.

These interview schedule templates were further slightly adapted to the specific case of the Genius of SPACE and Dwars River Projects respectively.

2.4 Global Literature Review

What are the benefits of water-related investments into nature in the peri-urban? A Global South perspective

Abstract

With rapid urbanisation occurring globally, peri-urban areas (transition spaces often affected by expansion processes of the city) become increasingly important as a source of ecosystem services to people yet are increasingly degraded. Nature-based solutions have been proposed to tackle many societal challenges, such as declining water quality, air quality and food security. Their advantage over traditional hard infrastructure solutions is thought to be in their ability to provide "co-benefits", or additional benefits. Despite the value of nature-based solutions, and the strategically important location of peri-urban areas, there is no synthesis on the benefits of implementation in these settings. With the rapid expansion of cities in the Global South, there is a need to understand what has been implemented in these nations, as well as what the impacts have been. In this study we systematically review the global peer-reviewed English-language literature and the South African grey-literature as a Global South case study. We endeavour to synthesize the benefits (also co-benefits), the quality of the evidence, and develop insights from exploring this from a Global South perspective. We found that the Global South's representation in international literature is low. The benefits of nature-based solutions in peri-urban areas were mostly found to be positive. However in general, nature-based solutions are not well empirically studied (many studies are conceptual or descriptive. Very few publications explicitly addressed the topic of co-benefits. Some important insights emerged by incorporating a Global South case study. Funding and governance are serious barriers for implementation for the Global South, compared to technology and innovation for the North. Benefits were disaggregated by socio-economic status and gender for the Global South and location for the Global North. Including the Global South perspective has widened the narrative and yielded important insights which advances the growing field of nature-based solutions. We make some recommendations for future research to strengthen the field of practice of nature-based solutions, with reference to the peri-urban.

Introduction

Nature-based solutions are defined as "*actions to protect, sustainably manage and restore natural or modified ecosystems that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits*" (IUCN, 2020) and are considered to be "*inspired by, supported by or copied from nature*" (European Union, 2015). Nature-based solutions therefore include concepts such as green and blue infrastructure, biomimicry as tools for ecologically sensitive development, conserving or rehabilitating natural ecosystems and/or the enhancement or creation of natural processes in modified or artificial ecosystems. They can be applied at micro- (e.g. within household) or macro- (e.g. landscape) scales (WWAP/UN-Water, 2018) and are considered to deliver multiple benefits. The water sector is likely to be most benefited by nature-based solutions, particularly in achieving progress towards sustainable human settlements, access to water supply and sanitation services, enhanced food production, and water-related disaster risk reduction. Water-related nature-based solutions are regarded as important for climate change response as they address availability as well as quality challenges (WWAP/UN-Water, 2018).

Considerable attention is currently focused on promoting and applying nature-based solutions in an urban context (Lafortezza *et al.*, 2018). However, peri-urban areas, transition spaces often affected by expansion processes of the city, remain under-studied (Ramírez-Agudelo *et al.*, 2020). Peri-urban areas may originally be natural or transformed open spaces such as woodlands, farmlands and nature reserves in the urban periphery. These peri-urban areas have historically played important role in development and sustenance of urban centres, provision of water-related ecosystem services, particularly water supply, wastewater management and flood control. However, with urban expansion, as natural environments get increasingly replaced by 'built' environment, pressures on these areas mount (Güneralp *et al.*, 2018). These include unregulated construction resulting in low-rise sprawl, inadequate environmental planning, overexploitation of water resources and the formation of camps for refugees or internally displaced people (Güneralp *et al.*, 2018; Butsch and Heinkel, 2020). There is need to find sustainable solutions to these challenges in the peri-urban.

Nature-based solutions for water-resource management in the peri-urban may hold potential, especially given that these approaches are thought to generate multiple co-benefits (Pagano *et al.*, 2019). There have been several international literature reviews on nature-based solutions. The first of these, in 2017, developed a framework for assessing and implementing the co-benefits (and costs) of nature-based solutions across elements of socio-cultural and socio-economic systems, biodiversity, ecosystems and climate in urban areas (Raymond *et al.*, 2017). The results, guided by a review of over 1700 documents from science and practice, demonstrated that nature-based solutions can have environmental, social and economic co-benefits and/or costs both within and across ten identified societal challenges (Raymond *et al.*, 2017). In 2019, another literature review addressed how nature based solutions contributed to priority societal challenges surrounding human well-being in the United Kingdom (Dick *et al.*, 2019). This study found that while there are many reviews and a clear evidence base linking certain nature-based solutions to various elements of human well-being, there has been no comprehensive mapping of these linkages across a range of habitats (Dick *et al.*, 2019).

In 2020 a review was performed on nature-based solutions for urban water management in European circular cities (Volkan Oral *et al.*, 2020). Three main findings are that nature-based solutions provide particular value for (i) flood and drought protection; (ii) the water-food-energy nexus; and (iii) water purification. This review also found that nature-based solutions provide additional co-benefits, such as increasing biodiversity, social benefits, and improving urban microclimate (Volkan Oral *et al.*, 2020). Also in 2020, a global review aimed at understanding the value and limits of nature-based solutions to climate change and other global challenges was undertaken (Seddon *et al.*, 2020). The main findings

included that nature-based solutions have become increasingly prevalent in climate policy, due to their potential for climate change adaptation as well as mitigation. Barriers to evidence-based implementation, and major financial and governance challenges to implementing nature-based solutions at scale are also discussed (Seddon *et al.*, 2020). Lastly, and most recently, an international literature review focussed on nature-based solutions for water-challenges in the peri-urban, considering challenges, lessons, barriers, and ecosystem services (Ramírez-Agudelo *et al.*, 2020).

Of all the reviews on nature-based solutions, none consider the impact of nature-based solutions in terms of improvements to society in the peri-urban. In addition, cities are expanding more rapidly in the Global South (Parnell and Walawege, 2011; Güneralp *et al.*, 2018; Pauleit *et al.*, 2019; Butsch and Heinkel, 2020) and therefore a focus on peri-urban areas for this region is needed. There is also a particular paucity of research in the Global South in general. These three issues intersect to present an interesting gap to explore further. Evidence as to these benefits may help to leverage investments into nature-based solutions at scale (Rebelo *et al.*, 2021). Therefore, we ask four research questions: (1) "What are the benefits of water-related investments into nature in the peri-urban?", (2) "What is the quality of this evidence?", (3) "Is there evidence of co-benefits of nature-based solutions?" and (4) "What insights can be gained from exploring this from a Global South perspective?" To address these questions we systematically review the global peer-reviewed English-language literature and the South African grey-literature as a Global South case study.

Methods

This systematic review followed a two-step approach. The first step was to analyse the global peer-reviewed, English-language literature for all dates until the date of search (**Table 2**). We performed a search in three databases: Scopus, ScienceDirect and Web of Science. We searched for the following keywords in 'all fields', but using a sequential approach for the synonyms for nature-based solutions (see **Table 2**):

TITLE + ABS + KEY = (("nature-based solution*" OR "nature based solution*" OR "water solution*" OR "ecolog* solution*" OR "greening" OR "biological solution*" OR "ecological infrastructure" OR "soft infrastructure" OR "green infrastructure") AND "water" AND ("peri-urban" OR "peri urban" OR "urban edge" OR "urban fringe" OR "rural urban nexus"))

The second step was to improve our understanding of what is happening in the Global South, given that it is under-represented in the international literature (Cummings and Hoebink, 2017; Güneralp *et al.*, 2018; Maas *et al.*, 2021). The concept of a gap between Global North and Global South is largely in terms of development and wealth. However, nations in the Global South are not homogenous, there is a great deal of variation, as some countries have above average GDP per capita (e.g. Argentina, Malaysia and Botswana). Similarly, some countries in the Global North would be considered 'poor' using the same measure (e.g. Ukraine). Therefore, to improve our understanding of what is happening in the Global South, we used a case study for a grey-literature analysis. South Africa was selected as a case study because it has a GDP per capita below average (~US$10 700) and yet is comparatively well represented in the literature relative to other nations in the Global South in general (Connell *et al.*, 2017; Medie and Kang, 2018). From South Africa we chose one national repository, for water-related research, that of the Water Research Commission: The Knowledge Hub (**http://search.wrc.org.za/#!/**). The Water Research Commission is a major water-research funder in South Africa (**Table 2**).

Table 2. *Literature search results of international databases: Scopus, ScienceDirect and Web of Science, as well as from a local database of grey literature from one country in the Global South. The database is the Knowledge Hub, which is the database of the Water Research Commission, the major water-research funder in South Africa.*

Database	[] + water + peri-urban	Number of articles	Date of search
Scopus	Nature-based solutions	5	01/08/2020
	Water-solutions	1	
	Ecological solutions	0	
	Greening	5	
	Biological solutions	0	
	Ecological infrastructure	1	
	Soft infrastructure	0	
	Green infrastructure	16	
ScienceDirect	Nature-based solutions	2	01/08/2020
	Water-solutions	0	
	Ecological solutions	0	
	Greening	24	
	Biological solutions	0	
	Ecological infrastructure	0	
	Soft infrastructure	0	
	Green infrastructure	6	
Web of Science	Nature-based solutions	4	01/08/2020
	Water-solutions	2	
	Ecological solutions	0	
	Greening	5	
	Biological solutions	0	
	Ecological infrastructure	0	
	Soft infrastructure	0	
	Green infrastructure	10	
Water Research Commission	Nature-based solutions	7	01/08/2020
	Water solutions	37	
	Ecological solutions	3	
	Greening	64	
	Biological solutions	1	
	Ecological infrastructure	66	
	Soft infrastructure	1	
	Green infrastructure	15	

The peer-reviewed and grey-literature search results yielded 70 publications, and 135 reports respectively. We screened all publications for relevance, and any not meeting acceptance criteria were rejected. The three criteria for acceptance were: (1) the publication considers the peri-urban, (2) the publication explicitly considers a nature-based solution (for example, we reviewed but then excluded an additional 25 documents that only considered water resource management, integrated water resource management, and soft infrastructure without an explicit nature-based solution aspect), (3) the publication is a peer-reviewed scientific publication, report, book chapter or magazine article (annual reports and conference synthesis reports were excluded). In total, 30 peer-reviewed and 115 grey-literature publications were rejected, resulting in a final selection of 40 and 20 peer-reviewed and grey-literature publications respectively.

From the final database of 60 publications, we extracted data according to a designed codebook (**Appendix 4**). Data collected included background information (e.g. on the country, location, scale and site characteristics), details about the nature-based solution considered, and then the results in terms benefits and co-benefits (e.g. ecosystem service provision, social impacts, economic impacts, as well as some other benefit categories). These results were collected into an excel database, and variables analysed. Where necessarily, variables were categorised into themes for sense-making of the data (e.g. nature-based solution group, societal and other benefits, potential trade-offs), see **Appendix 4**, *Supplementary Material*.

Results

The results are presented in five sections, which include (1) contextual results, and sections that address each of the four research questions: (2) "What are the benefits of water-related investments into nature in the peri-urban?", (3) "What is the quality of this evidence?", (4) "Is there evidence of co-benefits of nature-based solutions?" and (5) "What insights can be gained from exploring this from a Global South perspective?".

Contextual results

The representation of the Global South in the international literature is low with only 10 out of 40 publications from the Global South, with a further four representing countries both from the Global North and the Global South (**Figure 9**). Europe is well represented (e.g. Italy, Germany) in the international literature, as is the United States. From the South African grey-literature analysis, all 20 publications were from South Africa.

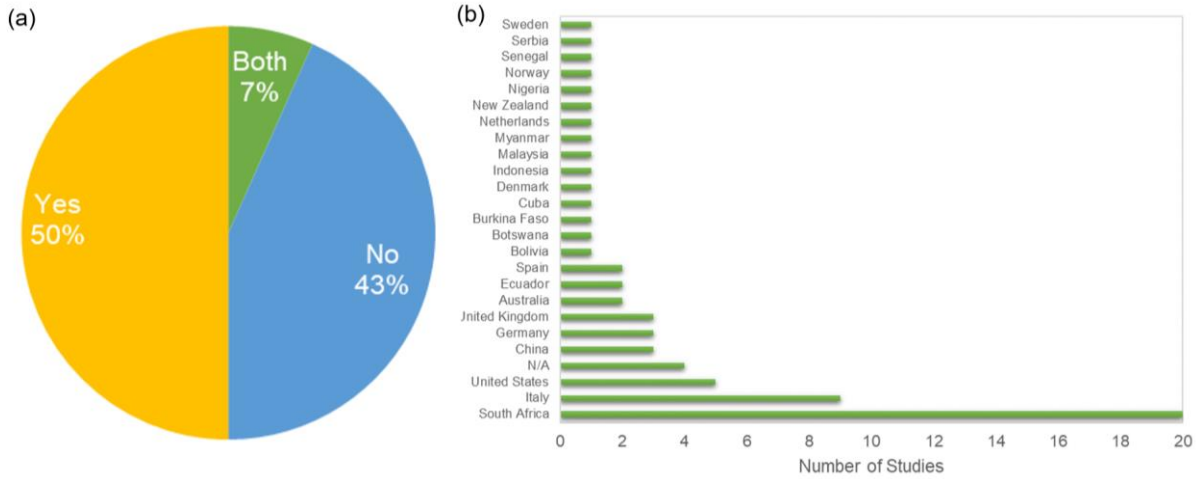


***Figure* 9.** *(a) Representation of the Global South publications in the database. Yellow represents the Global South (n=30), blue represents the Global North (n=26), and green represents publications that cover both (n=4). (b) The countries included in the literature review ordered by number of studies (n=60). Not applicable (N/A) refers to conceptual studies or global reviews.*

Most of the publications from the Global North were scientific journal articles, with only half the number from the Global South (**Figure 10**). The most common publication type from the South African

grey-literature analysis was reports, suggesting an implicit barrier preventing the Global South from publishing experiences in the international literature.

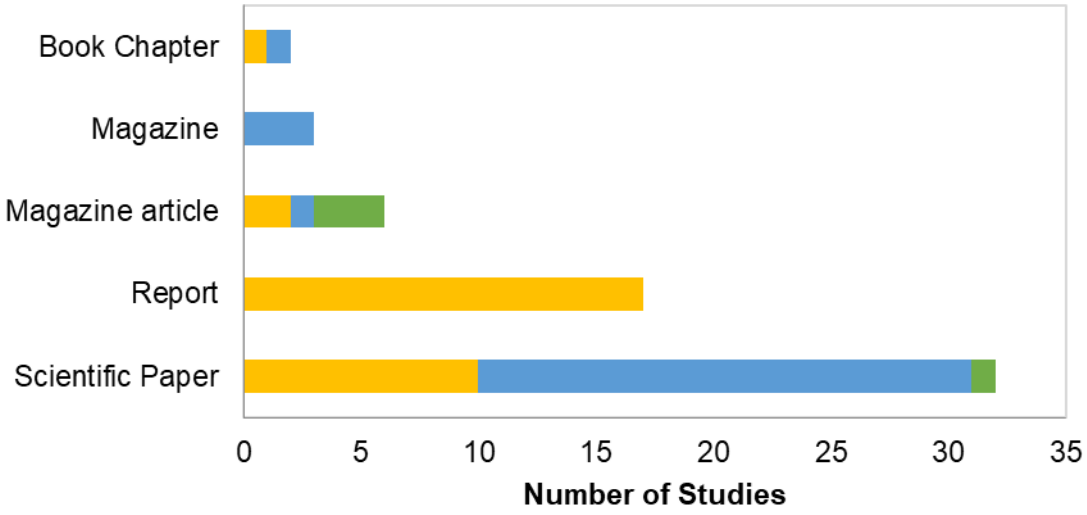


Figure 10. *Literature search results for the type of publication for the nature-based solution publications (n=60). Yellow represents the Global South (n=30), blue represents the Global North (n=26) and green represents publications that cover both (n=4).*

Most of the nature-based solutions were applied at a local scale (68%), and most of the studies used a conceptual methodology (60%) to quantify the ecosystem services provided by these nature-based solutions (**Figure 11**). In terms of nature-based solution publication contexts, only seven were explicitly peri-urban, the other 53 were combinations of urban, rural, and peri-urban (**Figure 12**). Most of the nature-based solutions studied were long-term investments, with very few being applied in the short-term, but there were a large number of studies that were purely theoretical (i.e. no nature-based solutions had yet been applied) (**Figure 12**).

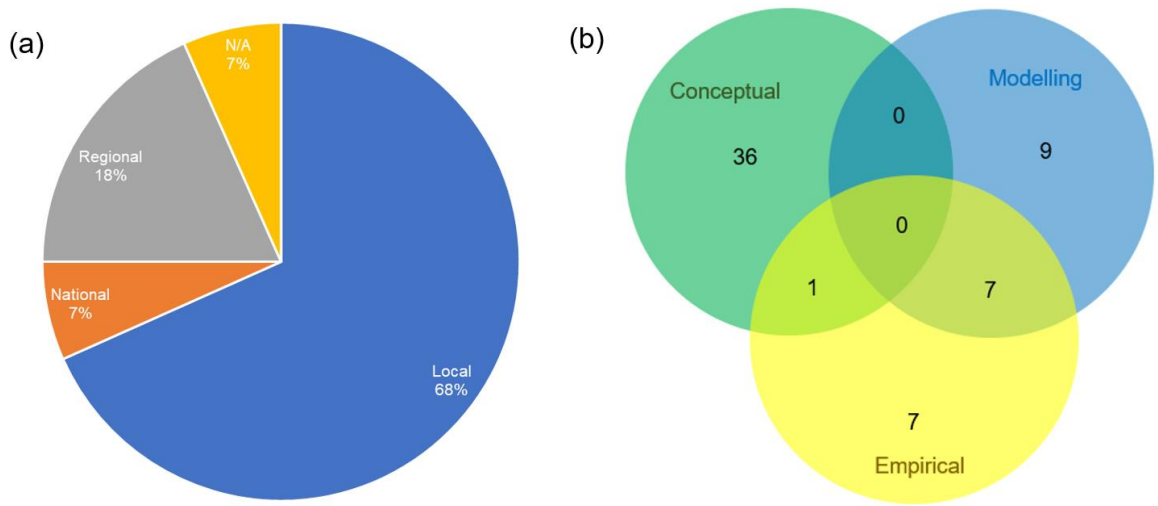


Figure 11. *(a) The focus scale of the nature-based solution projects: international, national, regional, local and not-applicable (N/A), which is where studies were theoretical, and no scale/potential scale was specified. (b) A Venn diagram of the methodologies used to quantify the benefits of the nature-based solutions: conceptual, modelling and empirical, and various combinations (n=60). See* ***Figure 9****,* ***Figure 10*** *and Supplementary Material for graphs showing differences between the Global North and Global South.*

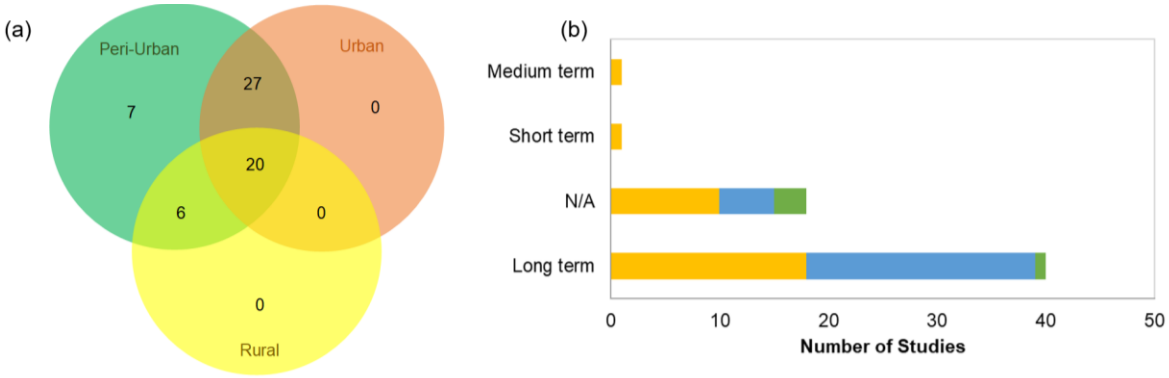


Figure 12. *(a) Venn diagram of the different study contexts: peri-urban, urban, and rural, and various combinations overall (n=60). (b) The timescale considered by the nature-based solution project (n=60). Yellow represents the Global South (n=30), blue represents the Global North (n=26) and green represents publications that cover both (n=4). See* ***Figure 9****,* ***Figure 10*** *and Supplementary Material for graphs showing differences between the Global North and Global South.*

Nature-based solutions were categorised into eight groups (**Figure 13**). Six groups emerged from the Global North literature, and eight from the Global South. Two nature-based solution categories: "ecosystem protection" and "restoration/rehabilitation" were found only in the Global South, whereas only one category, "green spaces" was unique to the Global North.

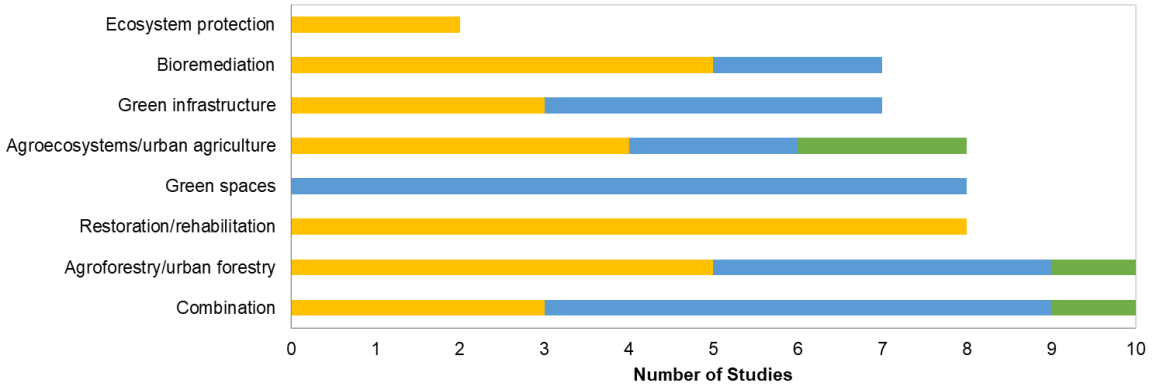


Figure 13. *Categorisation of nature-based solutions into eight groups (n=60). Yellow represents the Global South (n=30), blue represents the Global North (n=26), and green represents publications that cover both (n=4). See Supplementary Material for the definitions and examples of these groups respectively.*

Benefits of water-related investments into nature in the peri-urban

The majority of ecosystem services and benefits investigated by the peri-urban nature-based solution studies were suggested to increase following implementation (**Figure 14, Figure 15**). Only 1.1% of ecosystem services and 6.4% of societal, economic and livelihood benefits were described to have negative impacts. Some peri-urban nature-based solutions are better studied relative to others in terms of impacts on ecosystem services, including: "restoration/rehabilitation", "combination" (i.e. two or more different nature-based solution groups – see **Appendix 4**, *Supplementary Material*, for the full list), "agroforestry/urban forestry" and "agroecosystems/urban agriculture" (**Figure 14**). Conversely, ecosystem protection is poorly studied in terms of its impacts on ecosystem service provision in the nature-based solution literature. For some nature-based solutions, holistic views have not really been taken regarding ecosystem service measurement, with an overemphasis on certain services, like recreation and tourism for "green spaces" being prevalent. As with ecosystem services, some nature-based solutions, such as "combination", "agroforestry/urban forestry" and "agroecosystems/urban agriculture" are better studied than the others in terms of the societal, economic and livelihood benefits derived (**Figure 15**). Health and cost-effectiveness were the most measured societal, economic and livelihood benefits.

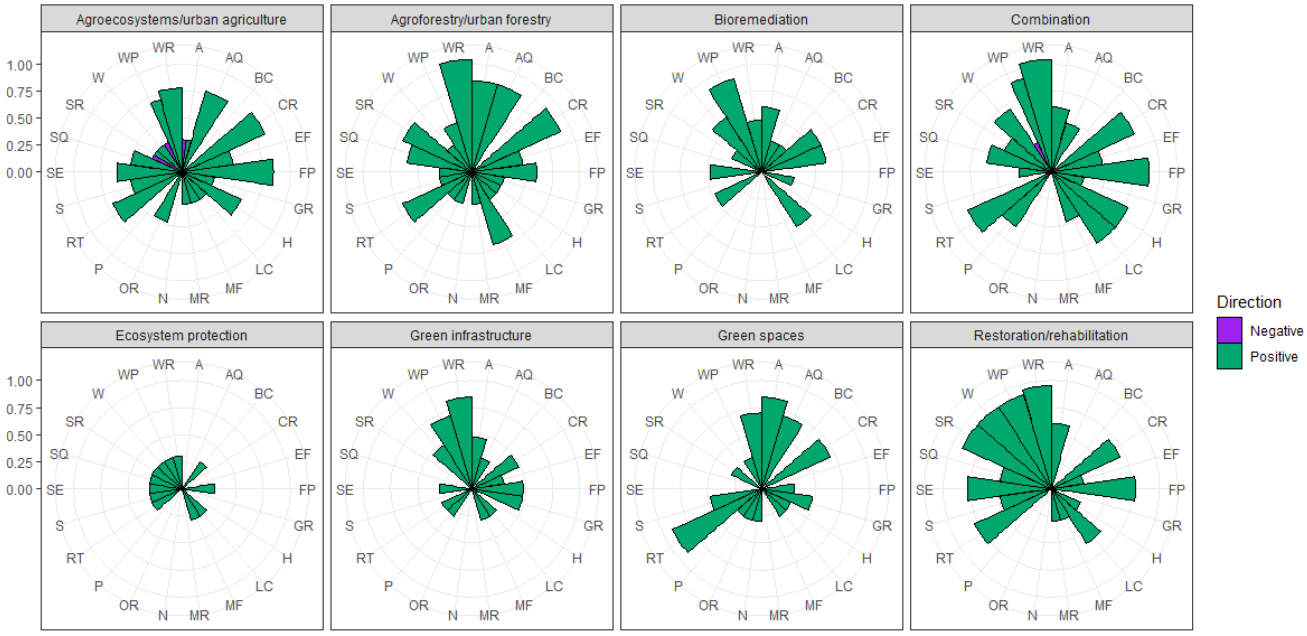


Figure 14. *Rose charts of the logn+1 of the number of cases indicating the direction of the benefit of implementing each nature-based solution (each box) according to the peer-reviewed and grey-literature on ecosystem services (the wedges) (n=60). The number of cases for each intervention is shown in* ***Figure 13****. Ecosystem services are indicated on the plot using the following symbols: A = Aesthetic Services, AQ = Air Quality Regulation, BC = Biological Control, CR = Climate Regulation, EF = Energy & Fuel Production, FP = Food Provision, GR = Genetic Resources, H = Heritage, Cultural, Bequest, Inspiration & Art, LC = Life Cycle Maintenance, MF = Materials & Fibre Production, MR = Medicinal Resources, N = Noise Regulation, OR = Ornamental Resources, P = Pollination, RT = Recreation & Tourism, SE = Scientific & Educational Services, SQ = Soil Quality Regulation, SR = Soil Retention, S = Symbolic, Sacred, Spiritual & Religious Services, W = Water Provision, WP = Water Purification, WR = Water Regulation. For a description of the 22 ecosystem service types, see* ***Table 3*** *and Supplementary Material.*

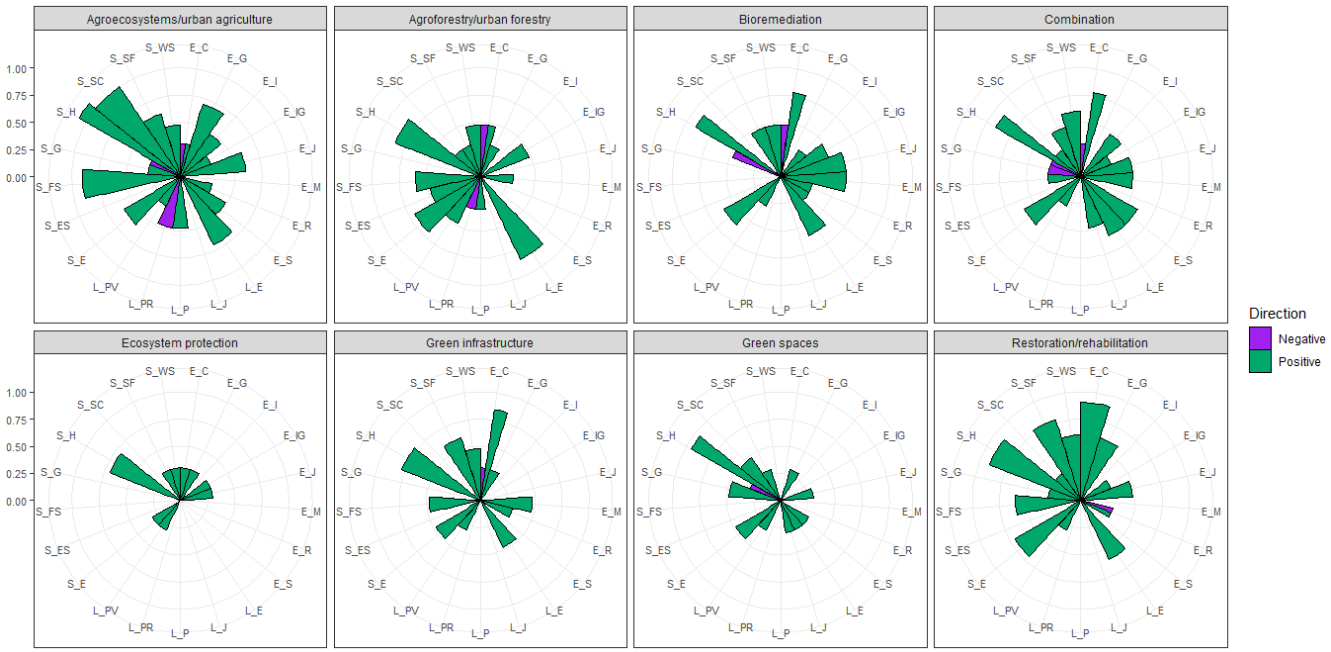


Figure 15. *Rose charts of the logn+1 of the number of cases indicating the direction of the benefit of implementing each nature-based solution (each box) according to the peer-reviewed and grey-literature on other benefits (the wedges) (n=104). The number of cases for each intervention is shown in Figure 13. Benefits are indicated on the plot using the following symbols: E_S = Circular economy, E_C = Cost effectiveness, E_G = Economic growth, E_IG = Industry growth, E_I = Infrastructure, E_J = Job creation, E_M = Market/commodity, E_R = Revenue, L_E = Employment/income, L_J = Justice, L_P = Poverty alleviation, L_PR = Property rights, L_PV = Property value, S_E = Education, S_ES = Energy security, S_FS = Food security, S_G = Good governance, S_H = Health & well-being, S_SF = Safety, S_SC = Social cohesion, and S_WS = Water security. The 'E' represents economic benefits, 'L' livelihood benefits and 'S' social benefits. For a description of the benefits herein, please refer to* ***Table 3*** *and Supplementary Material.*

Quality of this evidence

Most of the evidence underpinning the current understanding of ecosystem services and other benefits provided by peri-urban nature-based solutions is conceptual (**Figure 16**). The publications on "green spaces" are mainly underpinned by empirical and modelling methodologies, and the publications on "restoration/rehabilitation" are supported by mixed empirical and modelling methodologies. For societal, economic and livelihood benefits, the results were similar except that green infrastructure and bioremediation were also underpinned by mainly empirical and modelling methodologies (**Figure 17**).

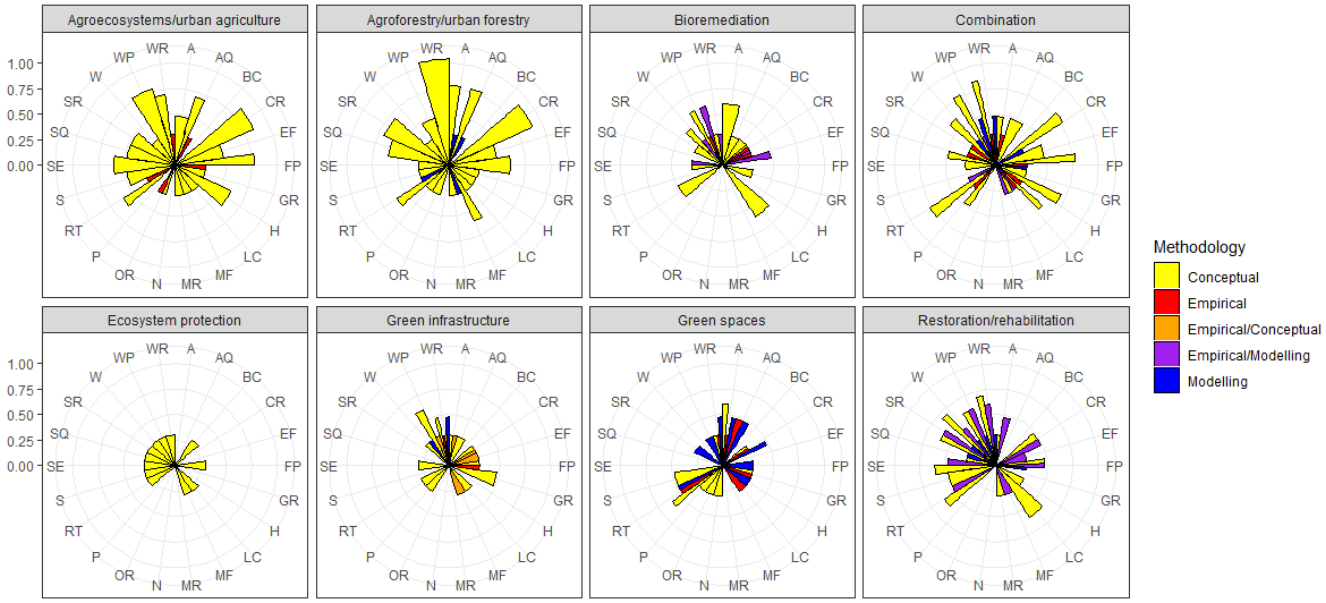


Figure 16. *Rose charts of the logn+1 of the number of cases indicating the methodology used for each study of nature-based solutions (each box) according to the peer-reviewed and grey-literature on ecosystem services (the wedges) (n=104). The number of cases for each intervention is shown in* ***Figure 13****. Ecosystem services are indicated on the plot using the following symbols: A = Aesthetic Services, AQ = Air Quality Regulation, BC = Biological Control, CR = Climate Regulation, EF = Energy & Fuel Production, FP = Food Provision, GR = Genetic Resources, H = Heritage, Cultural, Bequest, Inspiration & Art, LC = Life Cycle Maintenance, MF = Materials & Fibre Production, MR = Medicinal Resources, N = Noise Regulation, OR = Ornamental Resources, P = Pollination, RT = Recreation & Tourism, SE = Scientific & Educational Services, SQ = Soil Quality Regulation, SR = Soil Retention, S = Symbolic, Sacred, Spiritual & Religious Services, W = Water Provision, WP = Water Purification, WR = Water Regulation. For a description of the 22 ecosystem service types, see Supplementary Material.*

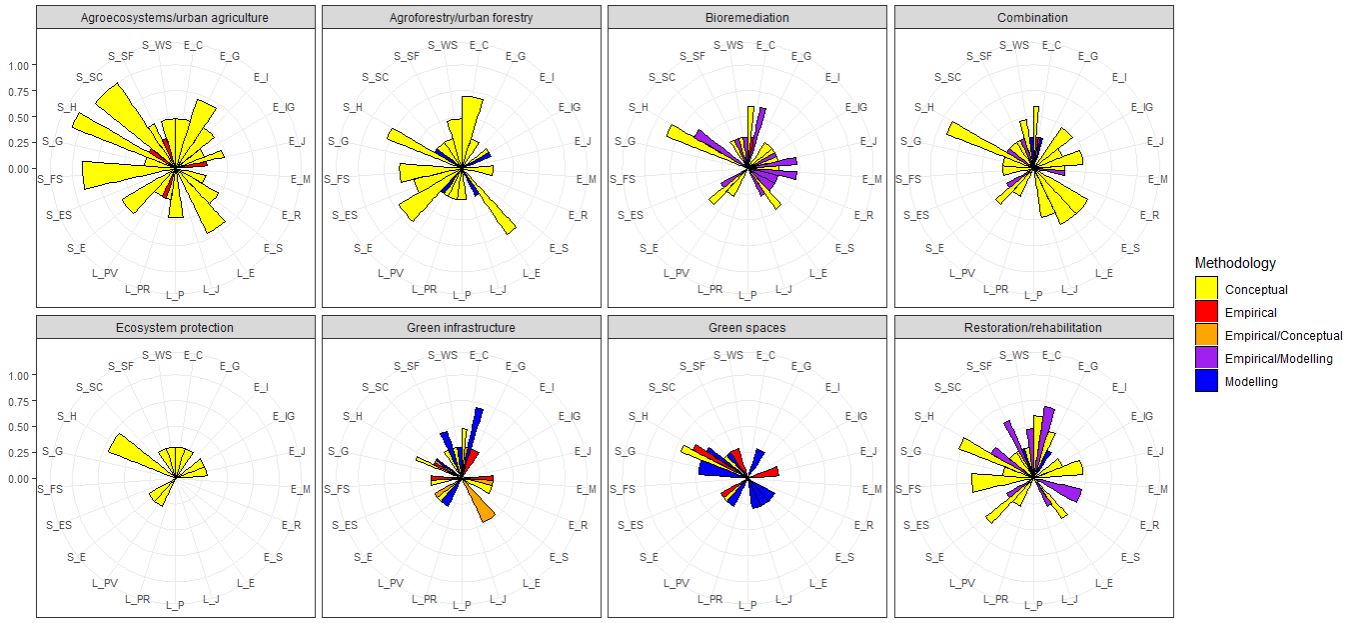


Figure 17. *Rose charts of the logn+1 of the number of cases indicating the methodology used for each study of nature-based solutions (each box) according to the peer-reviewed and grey-literature on other benefits (the wedges) (n=104). The number of cases for each intervention is shown in Figure 13. Benefits are indicated on the plot using the following symbols: E_S = Circular economy, E_C = Cost effectiveness, E_G = Economic growth, E_IG = Industry growth, E_I = Infrastructure, E_J = Job creation, E_M = Market/commodity, E_R = Revenue, L_E = Employment/income, L_J = Justice, L_P = Poverty alleviation, L_PR = Property rights, L_PV = Property value, S_E = Education, S_ES = Energy security, S_FS = Food security, S_G = Good governance, S_H = Health & well-being, S_SF = Safety, S_SC = Social cohesion, and S_WS = Water security. The 'E' represents economic benefits, 'L' livelihood benefits and 'S' social benefits. For a description of the benefits herein, please refer to Supplementary Material.*

In terms of uncertainty, 70% of the publications from the Global South attempted to quantify uncertainty, compared to only 62% for the Global North (**Figure 18**). Conversely for validation, the Global South scored much higher (67%) compared to the Global North (29%). The rehabilitation/restoration category had the highest number of publications that had uncertainty quantified and validated done.

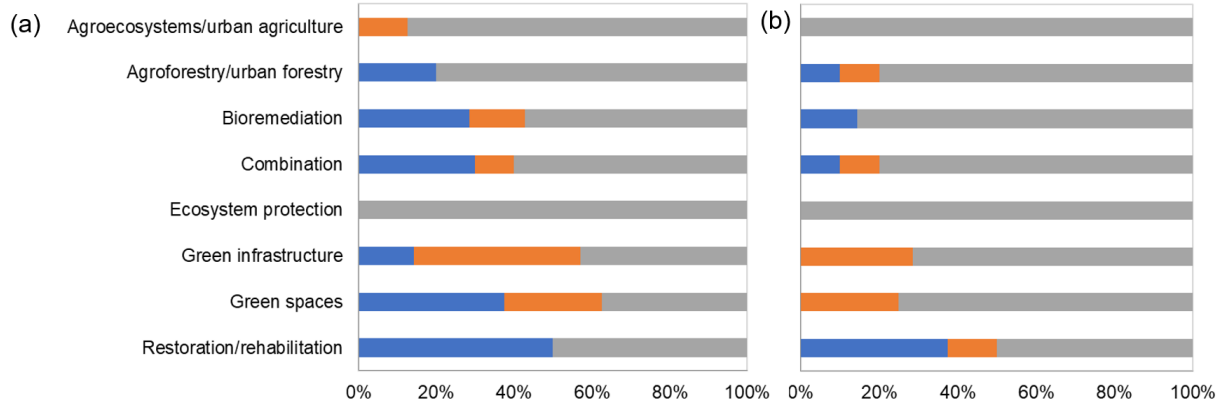


Figure 18. *The quality of evidence of the peer-reviewed and grey-literature publications: (a) whether uncertainty was quantified (n=23), and (b) whether validation was performed (n=13), both expressed as percentages per nature-based solution type. Grey = N/A, blue = done, and orange = not done.*

Evidence of co-benefits of nature-based solutions

For the publications which attempted to address whether the main objective (or benefit) of the peri-urban nature-based solutions was achieved or not (n=23), 95.6% described the objective as being met and only one as it not being met, and this study was from the Global South (**Figure 19**). The top five listed main objectives of peri-urban nature-based solutions were: water purification, water regulation, ecosystem services provision (in general), health and well-being and air quality regulation (**Table 4**).

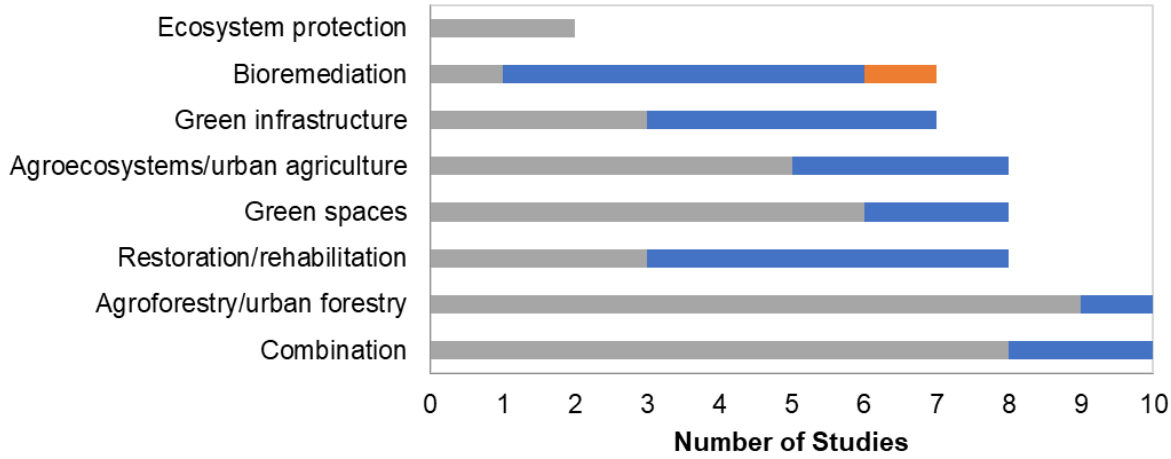


Figure 19. *The number of studies from the peer-reviewed and grey-literature describing that the main objective (main benefit) of the peri-urban nature-based solution had been met (n=60). Grey = N/A, blue = met, orange = not met. For details, see* ***Table 4****, Supplementary Material.*

Benefits in addition to the intended objective of the peri-urban nature-based solution, i.e. "co-benefits", were mentioned explicitly in 48% of the publications in the form of one of ten other synonyms (**Figure 20**). The term "co-benefits" only appeared in the peri-urban nature-based solution literature from 2015 onward and only appeared in 10% of the publications (**Figure 21**). Many of the terms are used relatively equally in the Global South and Global North, except for a few that were only listed once in a publication.

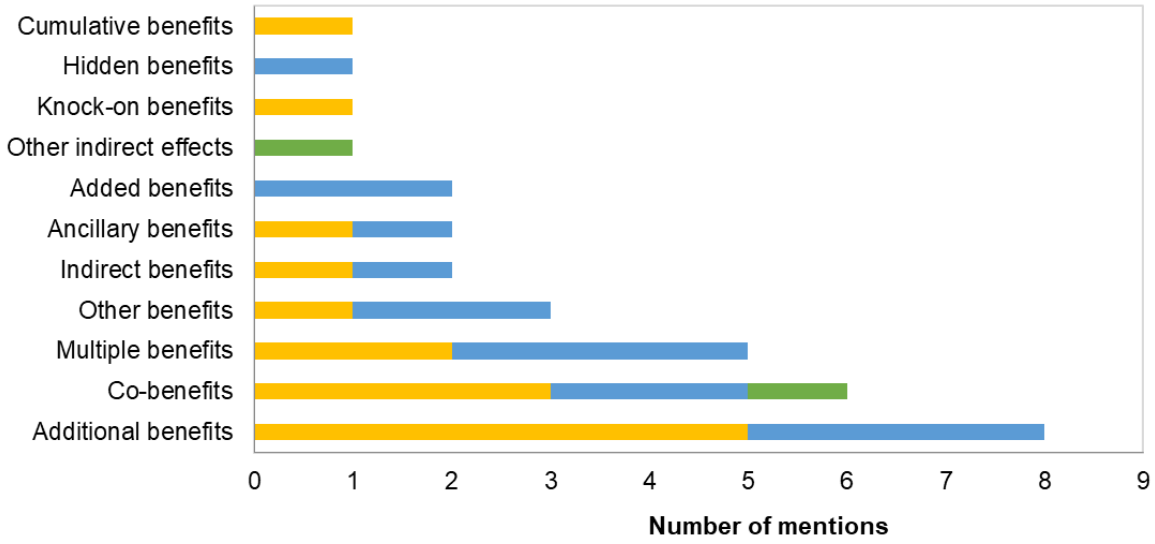


Figure 20. *The number of studies from the peer-reviewed and grey-literature mentioning co-benefits and related synonyms.*

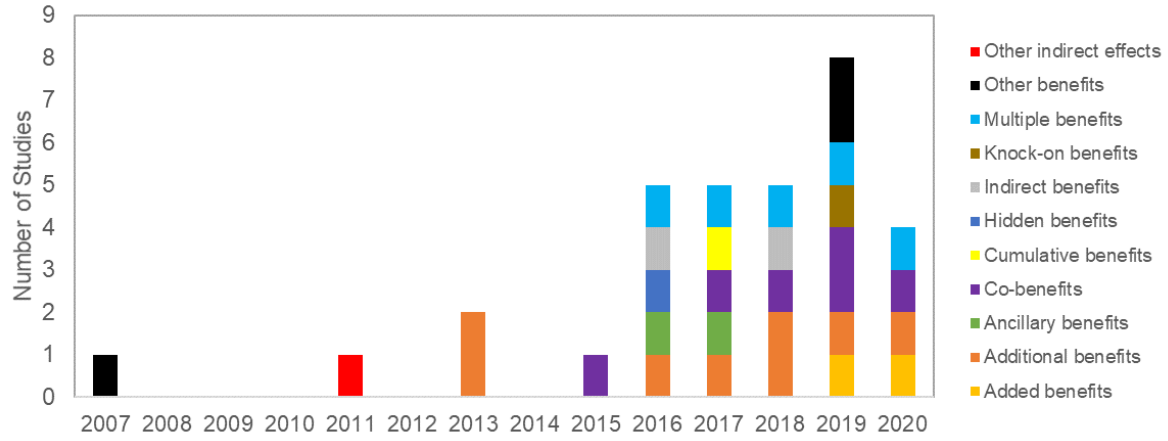


Figure 21. *Changes in nomenclature of 'co-benefits' over the years covered by this review in both peer-reviewed and grey-literature publications.*

Insights from a Global South perspective

Six enablers and 11 barriers were identified from the literature. The top three enablers for the Global North were listed as “stakeholder engagement and collaboration”, “innovation and technology”, and “planning, governance, policy”, which was quite similar to the top three enablers for the Global South: “stakeholder engagement and collaboration”, “planning, governance, policy” and “economic instruments and finances” (**Figure 22a**). The top three barriers for the Global North were listed as “urbanization and development”, “lack of data and technology” and “space and times limits”, whereas the top three barriers listed for the Global South were “governance challenges”, “urbanization and development” and “financial issues” (**Figure 22b**).

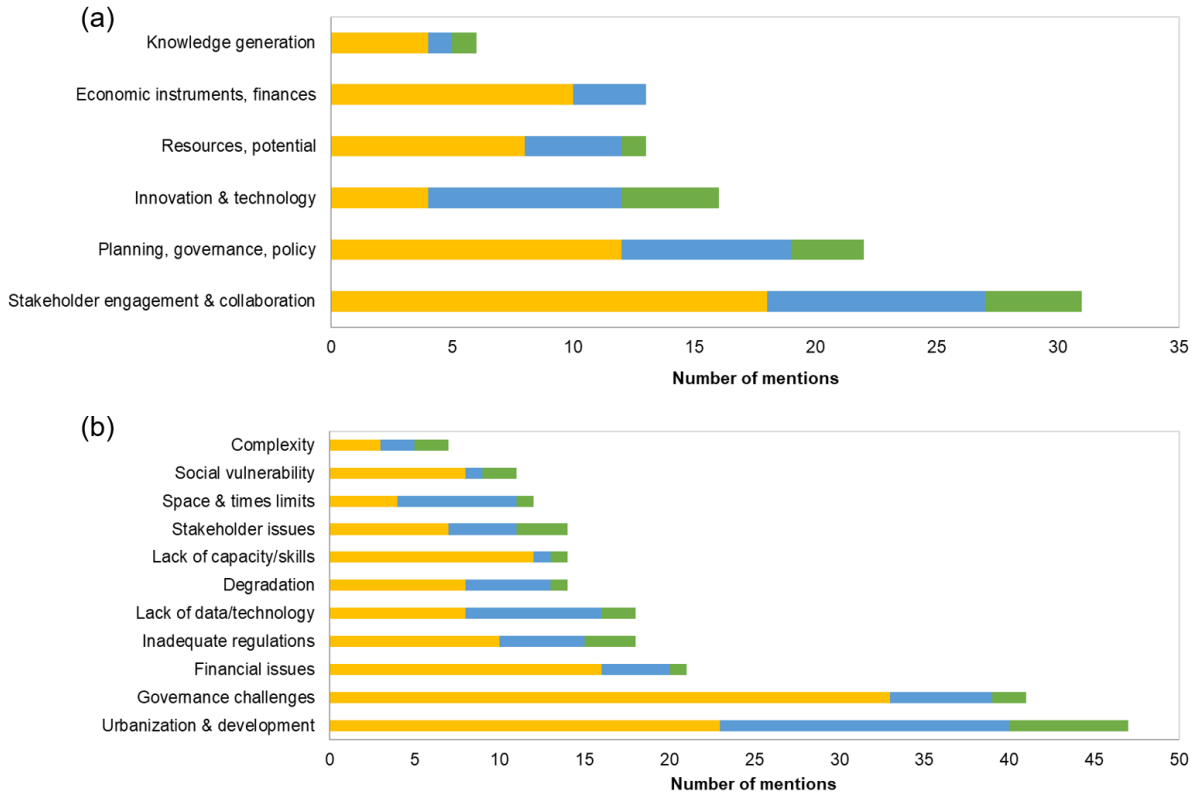


Figure 22. *A total of 48 and 55 peer-reviewed and grey-literature publications mentioned enablers (a) and barriers (b) to the application of nature-based solutions in the peri-urban respectively. A total of 101 enablers and 217 barriers were listed. Yellow represents the Global South, blue represents the Global North, and green represents publications that cover both. For a summary and detailed description of the enablers and barriers, see Supplementary Material.*

Overall, 26 publications (43%) described displacement of impacts or benefits (**Figure 23**). The Global South listed key impacts downstream in terms of water quality, followed by general ecosystem services and then flooding. The Global North mainly described downstream flooding as the major displacement of impacts. In terms of disaggregation of benefits, 17 (28%) publications suggested bias in the distribution of benefits, while the majority did not address this (**Figure 24**). For both the Global South and North, the biggest factor disaggregating benefits was location, and for the Global North this was followed to some extent by accessibility and socio-economic status. For the Global South socio-

economic status and gender were also very important in terms of a bias in benefits, and to a lesser extent accessibility.

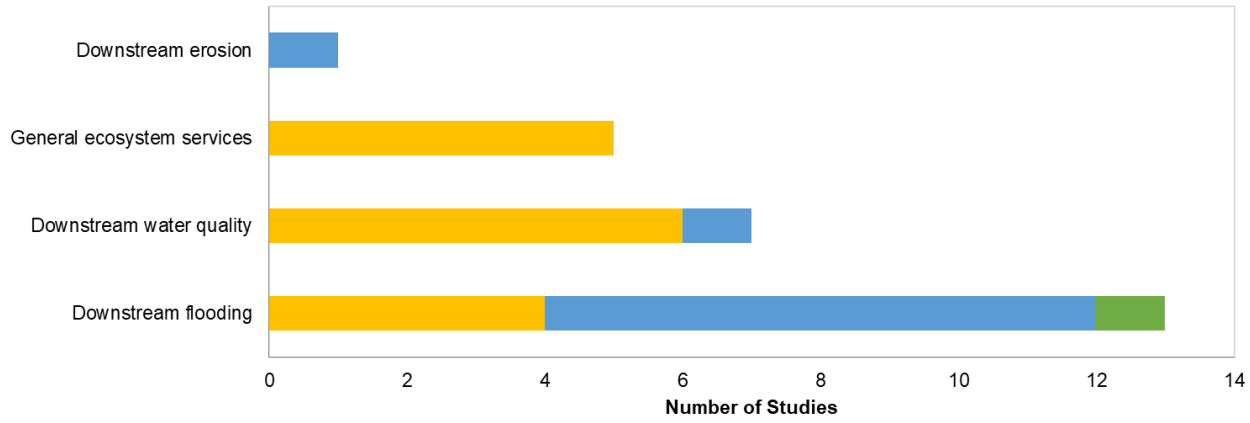


Figure 23. *Displacement of benefits and impacts of the peri-urban nature-based solutions that are documented in the peer-reviewed and grey-literature (n=26). Yellow represents the Global South (n=15), blue represents the Global North (n=10), and green represents publications that cover both (n=1). For a description of the displacements, see Supplementary Material.*

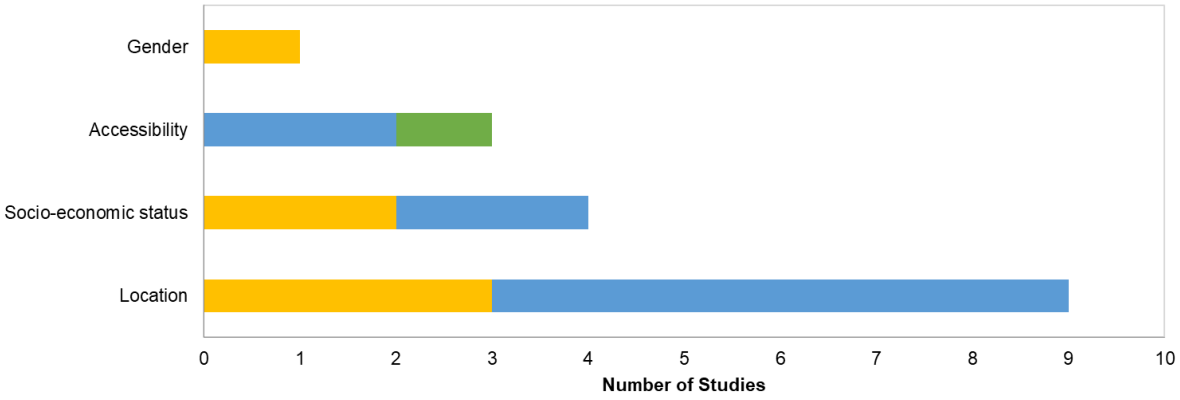


Figure 24. *Disaggregation of benefits of the peri-urban nature-based solutions according to the peer-reviewed and grey-literature (n=17). Yellow represents the Global South (n=6), blue represents the Global North (n=10), and green represents publications that cover both (n=1).*

Overall, 26 (43%) publications mentioned trade-offs when considering peri-urban nature-based solutions (**Figure 25**). For the Global South, the most important trade-offs mentioned (in terms of frequency) were those of conserving water resources versus economic development, risk versus return ratios, and provisioning versus regulating ecosystem services. For the Global North, the major trade-offs mentioned in the literature were green versus grey infrastructure, and land-use conflicts. Some examples of these land-use conflicts were the desire to protect biodiversity traded-off against fire risk of managing native vegetation, conservation versus urban sprawl and development versus allotments.

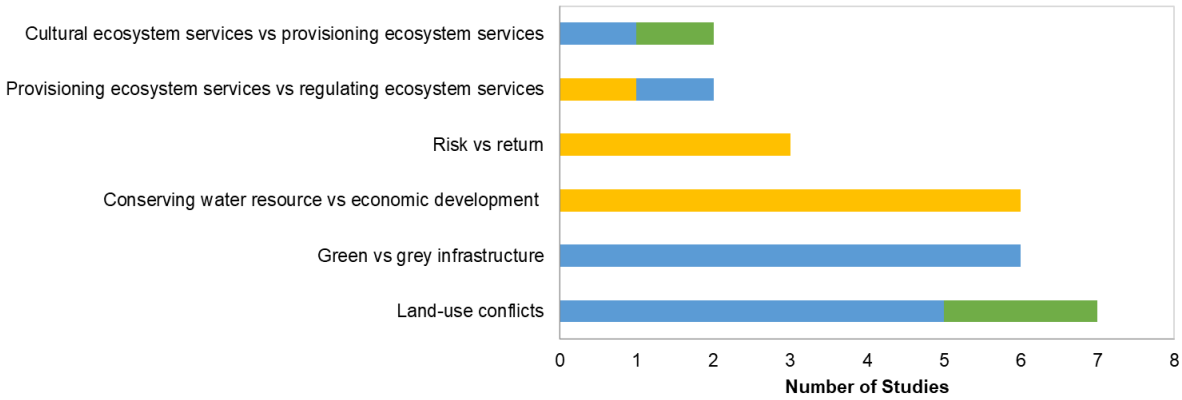


Figure 25. *Trade-offs mentioned by the peri-urban nature-based solutions studies in the peer-reviewed and grey-literature (n=26). Yellow represents the Global South (n=10), blue represents the Global North (n=13), and green represents publications that cover both (n=3).*

Discussion

Peri-urban areas are dynamic, heterogeneous and complex, which makes finding generally applicable solutions for planning and management challenging (La Rosa *et al.*, 2018). These areas are also understudied, which is reflected in the literature reviewed, where relatively few publications were available on nature-based solutions for water management in the peri-urban compared to, for example, urban systems (Volkan Oral *et al.*, 2020). In fact, many of the publications reviewed in this study only included peri-urban areas as part of a broader context (e.g. a regional approach) with only seven of the publications focussed explicitly on the peri-urban. We found that studies of nature-based solutions in the peri-urban are largely conceptual (i.e. theoretical or using qualitative approaches). Most of the nature-based solutions for water-management in the peri-urban described in the literature we reviewed were applied at a local scale, and for the long-term. It should be noted that a high proportion of these were existing land-uses (e.g. peri-urban/urban forestry and agriculture, natural areas such as native vegetation, green spaces like parks and allotments), with relatively few representing interventions (e.g. green infrastructure such as green roofs or constructed wetlands) per se.

This study grouped nature-based solutions for water management into eight categories. There may be some overlap between certain categories, for example green roofs (green infrastructure) and urban agriculture (agroecosystems/urban agriculture) where the purpose of the green roof is food production, however we grouped interventions according to their methods, not outcomes. Two of the eight categories deal with native ecosystems, either restoring them, or protecting them, i.e. investing in ecological infrastructure (Rebelo *et al.*, 2021). Three categories deal with other land-use types which may already be existing, such as forest, agriculture and green spaces, or may be created within peri-urban areas. Green infrastructure and bioremediation are two categories where specific interventions are applied. Typically, the “combination” category included cases where more holistic approaches were taken, combining many different types of nature-based solutions to solve water management issues. It is extremely important to emphasize the context of these nature-based solutions when screening for inclusion of legitimate interventions. For example, agriculture and forestry are not nature-based solutions in themselves. Where replacing a pristine ecosystem, both would be considered habitat destruction, however where replacing already existing traditional agriculture (e.g. implementation of more environmentally friendly practices), or when viewed against another

alternative (e.g. industry or urban areas), both may be considered beneficial in terms of ecosystem service provision and societal benefits and thus may be considered nature-based solutions.

There are quite a few studies that miss this nuance and either frame an unsustainable practice as a nature-based solution (e.g. traditional agriculture or forestry) or make unsubstantiated generalisations about nature-based solutions. One example is the issue of an overemphasis on indiscriminate tree planting instead of on ecological restoration (Silveira *et al.*, 2021). Some studies list the benefits of tree planting, without citing any sources (e.g. Valente *et al.*, 2019), and without citing any of the issues associated with this practice (e.g. impacts on water resources, respiratory issues), or make inappropriate generalisations of findings from other studies in other ecosystems or regions (Silveira *et al.*, 2021). Several the publications rejected during this review were as a result of them having nothing to do with nature-based solutions, despite referring to nature-based solutions in their publication. Some were even in direct conflict with nature, for example: agriculture versus conservation. A recent review found that nature-based solutions are still vaguely defined and have become a catchall phrase, resulting social and environmental justice being side-lined (Cousins, 2021). Another review included interventions which may not "meet guidelines for nature-based solutions in practice" because they felt that this evidence was needed to grow the understanding of what effective nature-based solutions are (Chausson *et al.*, 2020). There is an urgent need to clearly define what nature-based solutions are, and what they are not, and the critical importance of context.

The benefits of water-related investments into nature in the peri-urban

The impacts of nature-based solutions for water management in the peri-urban reviewed in this study were overwhelmingly positive, both in terms of ecosystem service provision and social, livelihood and economic benefits. There were eight negative economic impacts listed, which were all related to the lack of cost-effectiveness of the nature-based solution, or potential revenue losses. Lag effects was mentioned as a challenge: the passing of time between the investment and returns due to the long process of ecological restoration. Three publications mentioned negative impacts relating to land tenure (land-use conflicts) for agroforestry/urban forestry or agroecosystems/urban agriculture, for example that the land price and natural capital value of the soil are negatively related. Six negative social impacts were mentioned, related to health and well-being (e.g. negative risks from agroecosystems/urban agriculture), allergies to tree pollen (green spaces), and human-wildlife conflict (combination nature-based solution group).

This high incidence of positive outcomes for nature-based solutions is similar to the results of other reviews on nature-based solutions and ecological infrastructure (Chausson *et al.*, 2020; Rebelo *et al.*, 2021). However, most of this evidence was conceptual, and for most empirical studies, the evidence was gathered empirically for only one aspect, and the other benefits inferred and not measured. This highlights a critical research gap for more holistic measurement of ecosystem services of nature-based solutions for water management in the peri-urban (Boerema *et al.*, 2017; Chausson *et al.*, 2020). Similar to these results that knowledge on the benefits of ecosystem protection within a nature-based solution context is limited, an international review found that the evidence was biased toward the creation of established ecosystems and ecological restoration with only about a fifth of studies focussing on ecosystem protection (Chausson *et al.*, 2020).

Quality of the evidence base of the benefits of nature-based solutions for water management in the peri-urban

While most of the evidence of ecosystem services and other benefits provided by nature-based solutions to water management in the peri-urban is conceptual, we found marked differences among the various nature-based solution types. Agroforestry/urban forestry, agroecosystems/urban agriculture, combination and ecosystem protection nature-based solutions were mainly characterised by conceptual methodologies, and this presents a critical gap for future empirical research. Conversely the benefits of other nature-based solutions were relatively well substantiated by modelling and empirical research. In general, at least two-thirds of studies on nature-based solutions to water management in the peri-urban make a reasonable effort to quantify uncertainty, though we did not analyse how appropriate these methods were, only recorded if uncertainty was acknowledged or not. On the other hand, models were only validated in about half of all publications with several publications making no mention of any kind of validation of their outputs, which is of concern.

These findings are similar to that of a global review on whether ecosystem services are adequately quantified, that called for more field validation of these modelling results (Boerema *et al.*, 2017). Since nature-based solutions are a similar catchall phrase, it seems that similar challenges apply to this emerging field as well and presents a gap for future research. It is notable that the rehabilitation/restoration category had more rigour in terms of uncertainty quantified and validation done compared to other nature-based solutions groups. This may be because it is a much more established, highly regulated field of practice, with a set of global standards (Gann *et al.*, 2019). The clear definitions and standards of this established field may be worth consideration for the emerging field of nature-based solutions (Woodworth, 2017). This is especially in terms of avoiding damage caused by applying certain nature-based solutions in inappropriate places, or inappropriate interventions included as nature-based solutions (Cousins, 2021; Silveira *et al.*, 2021).

Evidence of co-benefits of nature-based solutions for water management in the peri-urban

The definition of nature-based solutions implies that there are multiple benefits arising from application, i.e. “simultaneously providing human well-being and biodiversity benefits” (IUCN, 2020), and “are thought to deliver multiple benefits to society” (WWAP/UN-Water, 2018). Despite the importance of co-benefits to the concept of nature-based solutions, only half of publications included in this review explicitly addressed the topic of multiple benefits, and very few explicitly mentioned co-benefits. Most nature-based solutions are designed to solve a specific challenge, in this case related to water-management in the peri-urban, besides all the co-benefits documented. All but one of the publications reviewed documented that the main objective, besides any co-benefits, of the nature-based solution was achieved. This could potentially be a bias of the publishing system, as it is possible that negative results may not be perceived as useful or worthwhile for publication. In some cases, however, there are not only win-win situations but important trade-offs to consider. Almost half of the peri-urban publications reviewed in this study mentioned a trade-off. The most mentioned trade-offs were land-use conflicts, green vs grey infrastructure and conserving water resources versus economic development. It has been noted in the literature that a focus on holistic ecosystem restoration rather than single solutions could help to minimize trade-offs and the importance of an evidence-based design to maximize synergies and minimize trade-offs has been noted (Seddon *et al.*, 2020). It is also critical to note that trade-offs are often viewed differently by different stakeholder groups and most of the studies reviewed did not aim to specifically investigate this aspect, therefore it is possible that this view is lacking from the literature to date (Seddon *et al.*, 2020). Certainly in the

Global South it has also been documented that people and institutions in peri-urban areas do not "have the power to negotiate their own interests" (Butsch and Heinkel, 2020).

Barriers and enablers to nature-based solution implementation for water management in the peri-urban

In a review of nature-based solutions in urban settings, key enablers and barriers to uptake and implementation were identified (Sarabi *et al.*, 2019). A research gap was identified for further research into barriers and opportunities associated with different types of nature-based solutions, as well as synergies and trade-offs. Six barriers and ten enablers were identified for urban applications. In the peri-urban, six enablers and eleven barriers were identified in this study, the inverse of that of urban areas. Perhaps this disparity is suggestive of the complexities of the peri-urban setting (La Rosa *et al.*, 2018), or alternatively a reflection of the attempt to explicitly incorporate the Global South, which faces many challenges or barriers. The top enabler that emerged from the review of peri-urban settings was stakeholder engagement and collaboration and the top barrier was urbanisation and development. The latter is unique to peri-urban settings when compared to the review on urban setting (Sarabi*et al.*, 2019). Inadequate financial resources, institutional fragmentation and path dependencies (which we considered as one category) and inadequate regulations were common to both urban and peri-urban areas (Sarabi *et al.*, 2019). A supportive policy context (i.e. plans, acts and legislations) were common to both settings as enablers. A study on water-based livelihoods in the peri-urban found that due to the inherent complexities of these settings, new planning mechanisms are needed that are more flexible and respond to these complexities, steering development towards sustainability (Butsch and Heinkel, 2020).

Insights gained from explicitly adding a Global South perspective

Exploring this topic in the grey literature has been identified as a key gap, due to the paucity of studies from the Global South (Chausson *et al.*, 2020). In our review of the international literature, we found that representation from the Global South was low, which is congruent with many other studies (Collyer, 2018; Maas *et al.*, 2021). Not only is the Global South under-represented in the top-publishing journals, but also as lead authors and this is reflected in knowledge systems in general (Collyer, 2018; Maas *et al.*, 2021). We therefore included a Global South case study of grey literature of South Africa. It is important to note that we only considered one problem (water management in the peri-urban) and one country in the Global South. The aim was not to draw conclusions for all other countries in the Global South, but simply to see whether any additional insights could be gained from this approach. In fact, it is well known that the Global South is not uniform in terms of socio-politics, history, population size and therefore their position in the economy of knowledge (Connell *et al.*, 2017; Medie and Kang, 2018).

The fact that we found quite a few studies that met our criteria in our Global South case study (mainly reports) that were not at all represented in the international peer-reviewed literature suggests that there is an implicit barrier preventing the Global South from publishing experiences in the international literature. For this case study, given the focus, we selected one repository in South Africa, and this is the Water Research Commission's Knowledge Hub. The South African Water Research Commission funds academic research related to water, however importantly it is the major funder of research by consultants. The currency for consultants is not publications in the same way as it is for academics, and this may be one reason why this research is not making it into the international peer-

reviewed literature. Therefore, a potential driver of the Global North-South disparities could be the funding process and linked incentives. For example, if national funding bodies like the Water Research Commission in the Global South wanted to support this research contributing to global knowledge, incentives to publish could be provided, or disbursement of funds could be made conditional to this. By changing reporting requirements, for example, local funders could incentivize and empower scientists from the Global South to publish internationally and make their research more accessible.

There is much literature on Global North-South imbalances and the mechanisms that reinforce them (Collyer, 2018). Some of these mechanisms that maintain inequality in knowledge systems are: market concentration, commodification, monopolisation, extraversion, intraversion, internationalisation and standardisation (Collyer, 2018). In Africa specifically, structural adjustment policies such as reduced funding for research and training, poorly stocked libraries, low salaries, and heavy teaching loads as well as poor institutional incentives may contribute to reinforcing that divide from within (Medie and Kang, 2018). There have been many recommendations on how to improve equality in knowledge systems, including that journal editors and editorial boards encourage submissions from the Global South and include the Global South as editors, that professional organisations sponsor research and writing workshops, and that individuals pursue cross regional collaborations (Medie and Kang, 2018; Maas *et al.*, 2021). For example, the publications from the Global South considered in this study had a slightly lower proportion of modelling and empirical studies compared to the Global North, which may suggest a need for capacity building or access to infrastructure and equipment for field monitoring. Conversely, the publications from the Global South that did use modelling or empirical methodology did better at providing some sort of estimate of uncertainty compared to the Global North. When it came to validation of model outputs, the Global South publications in this review performed twice as well compared to the Global North. This phenomenon may have something to do with the "presumption of universalism" that has been highlighted for the Global North (Collyer, 2018). Scholars in the Global South tend to name the location of their research and offer it as a case study, compared to those in the Global North where assumption of universal relevance and a capacity to produce generic claims is more common (Collyer, 2018). Perhaps this applies to validation and quantification of uncertainty for the Global North as well, but this hypothesis would need further specific investigation.

In terms of the nature-based solutions themselves, the key differences between North and South was that "ecosystem protection" and "restoration/rehabilitation" were found only in the Global South, whereas "green spaces" as a nature-based solution was unique to the Global North. This may be explained by the relative proportions of indigenous ecosystems that remain surrounding cities which presumably differs between the Global North and South, or it may be a result of the rapidly growing cities of the Global South, peri-urban areas expanding into natural ecosystems (Parnell and Walawege, 2011; Güneralp *et al.*, 2018; Pauleit *et al.*, 2019; Butsch and Heinkel, 2020). The enablers for application of nature-based solutions for water management in the peri-urban were similar for the Global North and South, with the key difference being innovation and technology for the North, and economic instruments and finances for the Global South. This may speak to the need for the Global South to come up with creative financial solutions given the general lack of funding (Rebelo *et al.*, 2021). The barriers on the other hand were quite different between the North and South, except that urbanization and development was a universal problem. The Global North listed issues such as the lack of data and technology and space and time limits, whereas the Global South was limited by funding and governance challenges. In this study, the key downstream benefit of nature-based solutions in the Global South was documented as improved water quality, whereas for the Global North it was the attenuation of downstream flooding. The importance of considering off-stage

ecosystem service burdens, and in this case benefits, has been highlighted in the literature (Pascual *et al.*, 2017).

Both the Global South and Global North had some disaggregation of benefits, however for the North the biggest factors were location and accessibility whereas for the Global South it was socio-economic status and gender. This wealth and gender disparity in the Global South underscores the importance of considering justice in nature-based solution pathways (Cousins, 2021). The most important trade-off for the Global South in terms of frequency of mentions, was that of conserving water resources versus economic development, and for the Global North: green versus grey infrastructure. It is clear that there are some key differences between the Global South and North, and an entirely different picture would have emerged from this review if the Global South perspective had not been represented through the inclusion of this grey-literature case study. We acknowledge that including grey-literature is a challenge, especially in countries where it is not available in English, however this study demonstrates that it is possible through a case study of reasonable scope, and that it is beneficial in terms of widening the perspective. We recommend both that these imbalances in the knowledge system are addressed, and that until they are in balance, the Global South perspective is included in the narrative in creative ways.

Conclusion

This study addressed a critical gap in the nature-based solution knowledge system, both in terms of focussing on the understudied peri-urban setting, but also in considering the Global South through a case study of grey literature in South Africa related to nature-based solutions for water management. We found that including the Global South perspective has widened the narrative and yielded important insights which advances the growing field of nature-based solutions. In addition, this international review has highlighted some specific knowledge gaps for future study:

- More holistic measurement of ecosystem services is needed for nature-based solutions for water management in the peri-urban.
- More empirical research is needed on the ecosystem services and other benefits of agroforestry/urban forestry, agroecosystems/urban agriculture, combination and ecosystem protection as nature-based solutions to water management in the peri-urban.
- In general validation was poor, and field validation of modelling results is recommended, as well as better quality control by journals and editors.

To address critical water-related issues in the peri-urban, it is important to have a clearly defined field of practice and standards for nature-based solutions. To leverage investment and further support on the advent of many supportive initiatives, such as the United Nations Decade on Ecosystem Restoration starting in 2021, it is critical to build a strong evidence base of the benefits, as well as to minimize potential negative effects, downstream impacts and trade-offs to society through research.

Supplementary Material – Can be found in Appendix 4

3. Results and Discussion

This section is divided into four main parts, each fulfilling the project outputs (products) described in **Section 1.2**, and being presented as 'standalone units', which in many cases include introductions, method, results and discussion as well as references. These four parts are:

1. The narrative report: case study results from the Genius of SPACE and Dwars River Projects.
2. The case study briefs from the Genius of SPACE and Dwars River Projects.
3. The photo stories from the Genius of SPACE and Dwars River Projects.
4. An international literature review.

3.1 Narrative Reports for the South African case studies

3.1.1 The sustainability of the Genius of SPACE Project according to the NATWiP Framework

Abstract

The Genius of SPACE (Systems for People's Access to a Clean Environment) was a pilot aimed to apply Nature-Based Solutions (NBS) to treat and manage wastewater and greywater entering the stormwater system, as well as the management of solid waste while empowering local community members, improving living conditions and promoting social upliftment. Langrug, South Africa, is a relatively recently formed and continuously growing informal settlement, where wastewater and solid waste accumulate in the streets due to lack of service provision, sewerage, and surface hardening, leading to localised flooding, disease risk and associated health issues. The Stiebeuel River drains the Langrug Catchment (about 4.37 km^2) and enters the Berg River where polluted water emanating from the settlement and eutrophication cause issues for river health and agriculture downstream. The NBS involved the installation of 27 greywater disposal points, underground wastewater pipes, permeable paving, grading and pavement construction and 15 tree gardens for water infiltration. Semi-structured interviews were conducted with both Langrug community members (n=23) and actors involved in the implementation process (n=10) to assess whether the project was successful and what the major barriers are when implementing NBS in such contexts. The project was considered a failure by implementers and therefore the second phase of the project was never realised, which was geared towards generating income and in turn, maintaining service provision. The project was somewhat successful in cleaning the environment and the community experienced benefits regarding health and well-being, ecosystem service provision, education, and social cohesion. Key challenges during the implementation included complex social and institutional issues including unsustainable funding mechanisms, social vulnerabilities, and lack of stakeholder support. Due to these challenges, it was proposed that the experimentation of NBS is conducted in higher-income areas with greater capacities to cope with a failed system and that financing mechanisms are altered to overcome budget constraints experienced in the public sector. Despite the complex challenges, there was a sense of prosperity when the NBS was functioning, and the community would like it to be reinitiated. Valuable lessons can be learnt from this case study to improve success in future applications, specifically in the context of the global south.

Introduction

Water is a basic ingredient in the products we manufacture and consume daily, and it is so fundamental to our global economy that it is prioritized as the sixth Sustainable Development Goal (SDG) by the United Nations – clean water and sanitation. Managing freshwater sources successfully has become imperative for sustainable economic development as water is needed to achieve practically all seventeen SDGs. Additionally, a significant proportion of stress caused by climate change is through water; droughts, flooding, increased extreme weather patterns, and related impacts on water and sanitation infrastructure. This suggests an integrated method to catchment management is vital for securing high-quality water over various spatial and temporal scales (Le Roux *et al.*, 2019).

The challenges experienced on an over-populated, water-stressed planet are exacerbated by the significant proportion of people who live in informal settlements or so-called "slums." Almost one-quarter of the global population is estimated to reside in informal settlements (Hermanus and Andrew, 2018). Informal settlements are also widespread in South Africa with 1.25 million households in these areas recorded in 2011 (*StatsSA*, 2012). Furthermore, many informal settlements in South Africa are relatively recently formed due to local and international immigration and are characterised by insufficient basic services such as water and sanitation, overcrowding, all exacerbated by rapid growth (Pieterse, 2008). The Western Cape is a popular destination for job-seekers with a net immigration of 129 400 people from 2001-2006 which was 4.4% of the total population at the time (Lemanski, 2007). The poor conditions compromise the health and well-being of people (Olsson, 2017), and the large influx of people place stress on employment structures. Most of these people form part of the informal sector of which 75% earn less than R1 000 per month (Lemanski, 2007). The number of people residing in informal settlements is predicted to increase as a result of urbanization (Hermanus & Andrew, 2018). Global urbanisation and its implications create opportunities to investigate concepts such as Nature-Based Solutions (NBS) to enhance sustainability in urban areas (Wendling *et al.*, 2018). These solutions present an opportunity in dynamic informal settlements where traditional infrastructure cannot keep pace with migration.

Water insecurity not only affects businesses (economic risks), but it is also a risk for human well-being and health (social risks). Both economic and social dimensions of sustainability rely on the environmental dimension which explains the interrelatedness and complexity of water-associated challenges. With anthropogenically induced climate change that affects water cycles globally, coupled with population growth, sustainable development is undermined and ultimately compromises the ecological integrity of ecosystems (Cobbinah *et al.,* 2015). Sachs (2015) emphasises the relevance of resilience in urban ecosystems, specifically in the context of adjusting to rapid urbanization associated with climate change. Improving the quality and quantity of freshwater sources while ensuring resilience in ecosystems requires a paradigm shift to multi-stakeholder and bottom-up methods (Hermanus & Andrew, 2018). The inclusion of multiple stakeholders and adaptive management approaches (DEADP, 2018) must be incorporated in dynamic socio-ecological systems, as opposed to previously rigid "mechanistic" approaches. It is also beneficial if the provision of services are implemented via bottom-up approaches as opposed to top-down methods, especially since municipal governments are legally mandated to deliver essential services in these settlements, however, are limited by human resource capacity and budgetary challenges (Hermanus & Andrew, 2018), suggesting innovative governance is required (Wendling *et al.*, 2018). According to Mander *et al.* (2015), municipalities have failed to provide these basic services to approximately 13% of households in South Africa – that account for informal settlements – which emphasises the obligation to implement collaborative, community-driven approaches to build and manage "green" infrastructure solutions.

Implementing interdisciplinary NBS can present opportunities to address some of these complexities and therefore this case study evaluates the Genius of SPACE (Systems for People's Access to a Clean

Environment) project in the Western Cape, South Africa. The project aimed to treat and manage wastewater and greywater entering the stormwater system, as well as the management of solid waste while empowering local community members, improving living conditions and promoting social upliftment (DEADP, 2018). Due to the insufficient water and sanitation services in the informal settlement of Langrug, wastewater and solid waste accumulate in the streets which significantly contribute to downstream water pollution in the Berg River (Hermanus & Andrew, 2018). The Berg River catchment supports the agricultural industry and associated markets that the Western Cape province relies on and pollution threatens international certification (DEADP, 2017), highlighting the need for solutions. The implementation of NBS is stated to create several opportunities for social transformation and enhanced social inclusiveness in urban areas (Wendling *et al.*, 2018). The overarching aim of the project was environmentally focussed, improving water quality and ecosystem functioning. The project aimed to generate several co-benefits including socio-economic opportunities, social development and skills training related to biomimicry and improved health and sanitation (DEADP, 2018). In addition, the project incorporated collective decision-making processes and infrastructure was community-owned and managed which reinforced the idea of systems-thinking and adaptive management (Wolfaardt, 2017).

The Genius of SPACE project took a socio-ecological systems approach to build resilience both socially and ecologically via methods such as community engagement and the development of "green" infrastructure (Fischer *et al.*, 2015). Ultimately the application of NBS promotes stability and resilience in an ecological sense as the diversity of fauna and flora which are self-sustaining and self-regulating contribute to functional redundancy. With an enhanced genetic diversity resulting in more redundant species (i.e. species performing similar functions), the system is buffered against the loss of an individual species (Biggs *et al.*, 2020). Thus, diverse systems have a greater capacity to resist environmental pressures and quickly recover post-disturbance via positive feedback loops (Ziervogel *et al.*, 2017). Similarly, in a social context, a diverse and equitable culture encompasses individuals with various fields of knowledge and perspectives that allow for the development of vigorous interventions that can be applied to various aspects of a system (Jha *et al.*, 2013). Meerow *et al.* (2016) propose, and specifically in the context of informal settlements, that these socio-ecological systems should not only withstand shocks and disturbances, and recover to their previous state, but enhance the overall well-being of socio-ecological systems as conditions in these settlements must be surpassed, not merely preserved. Resilience thinking in the context of the Genius of SPACE project serves as a framework to comprehend how incremental, participatory, and investigative "green" infrastructure adds value to socio-ecological systems (Hermanus & Andrew, 2018).

2. Project aim and key questions

The overarching aim of this study is to assess the context, process, and results of the NBS: Genius of SPACE, according to the Lima *et al.* (2020) framework (**Figure 26**). This project forms one of the case studies of the Nature-Based Solutions for Water Management in the Peri-urban (NATWiP) project, which aims to take a systematic perspective on water-related NBS, particularly focussing on resilience, adaptation, complexity, and uncertainty for various peri-urban contexts. The NATWiP project is contributing to closing the water cycle gap (i.e. bridge the gap between demand and supply of water, enabling the sustainable management of water) by exploring the potential that NBS offer to address water management challenges in areas that have been neglected as they lie in the transition zones between the rural and urban environment. The project aims to investigate results based on all three pillars of sustainable development namely, social, economic, and environmental dimensions.

To evaluate whether the nature-inspired, adaptive management approach was sustainable and in turn, can be applied elsewhere, three key questions will be addressed:

1. Has the NBS been successful in the medium-term?
2. What are the main challenges/barriers to the implementation of the NBS?

3. What socio-economic-policy and governance context would favour the implementation of these NBS projects in the peri-urban context?

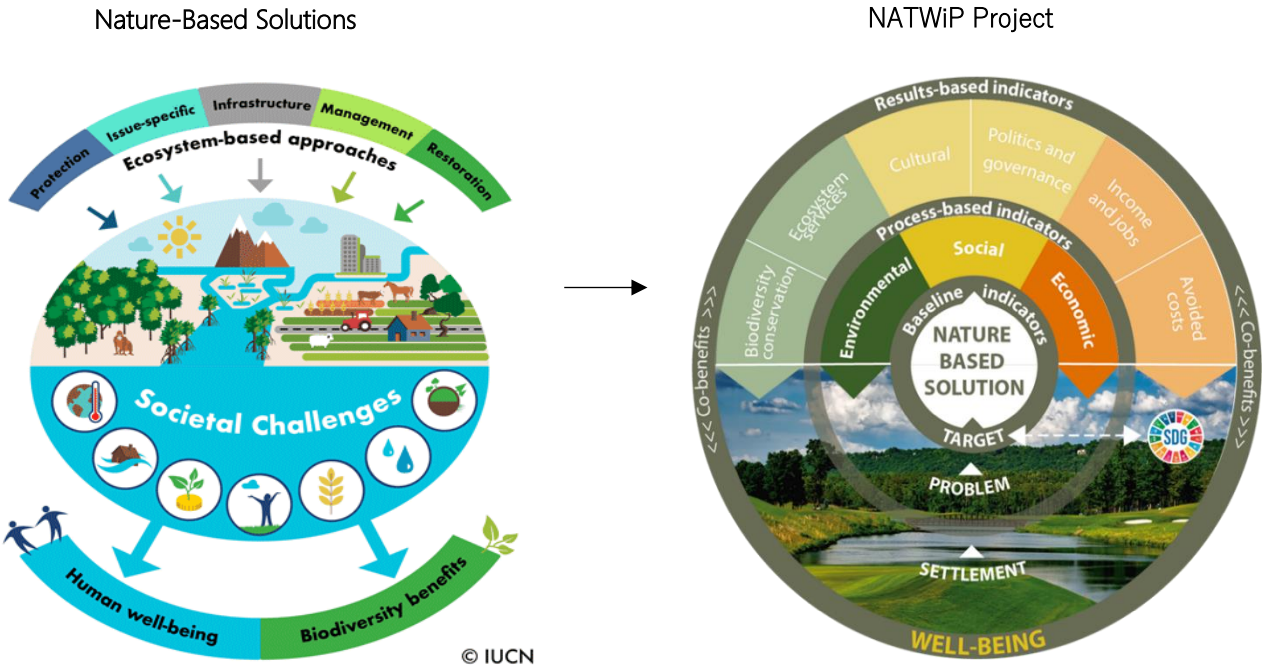


***Figure 26**: Conceptual framework for nature-based solutions (source, IUCN) and indicators to assess nature-based solutions in the peri-urban Lima et al. (2020).*

It is evident that managing freshwater ecosystems is essential for achieving all the SDGs which include all three dimensions – social, economic, and environmental. Despite the growing interest and innovation related to water management, managing this valuable resource across the value chain is intricate as it is extremely site-and-context-specific. Although extensive research has been performed in this informal settlement and on the Genius of SPACE project itself, this study includes the views of the community from Langrug themselves and therefore acknowledges the perspectives from both the implementation side and the receiving side of the NBS. Moreover, baseline-indicators are essentially compared with results-based indicators which suggest an anecdotal before and after comparison of the NBS was conducted which advances our understanding of the operationalization and management of "green" interventions. The Genius of SPACE project is one of many case studies across the globe which allows for researchers to explore water targets for these site-specific challenges and therefore require a unique implementation.

3. Study area

3.1 Physical context

The study is situated in a small (4.37 km^2), informally settled peri-urban catchment drained by the Stiebeuel River (Fell, 2017, **Figure 27**). The Stiebeuel River meanders through the low-income area of Langrug, Groendal and other land uses and ultimately enters the Berg River (Cameron, 2018). The settlement is called Langrug, which is encroaching up the mountain slopes and is found approximately 5 km north-west of and on the periphery of the wealthy town of Franschhoek in the Western Cape of South Africa (Armitage *et al.*, 2009). The steep slope on which the settlement is founded consists of talus material including clay and sandy loam soils, which exacerbates the poor drainage and infiltration, as the soil is considered functionally impervious (Fell, 2017). Heavy winter rains wash contaminated runoff, consisting of litter, sediments, nutrients, and additional pollutants, into the

stormwater system which feeds into the Berg River (Hermanus and Andrew, 2018). Greywater samples running into the Berg River contained significant amounts of faecal coliforms such as nitrogen, phosphorous, ammonia, suspended solids and *Escherichia coli* (Ravenscroft and Harris, 2017).

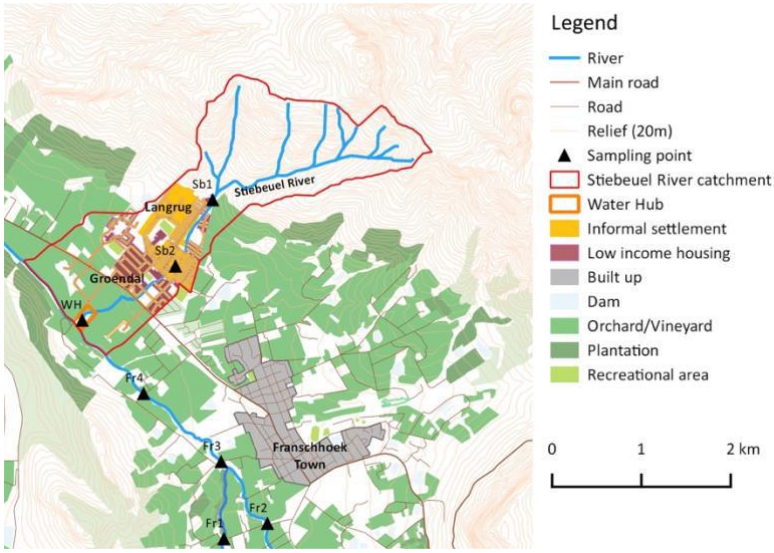


Figure 27: *The Stiebeuel River catchment, Franschhoek (Cameron, 2018).*

3.2 Socio-economic context

According to Winter (2016), 6000 people reside in Langrug and the area comprises approximately 2500 densely packed homes that are constructed from flimsy, scrap materials (called "shacks") which make residents vulnerable to floods and heat. Langrug comprises three main zones, namely, Mandela Park, Nkanini and Zwelitsha (**Figure 28**) and is estimated to be 26-27 years old. Blocks S and T were used to pilot the Genius of SPACE project (Hermanus & Andrew, 2018). Residents in Langrug mostly originate from the Eastern Cape (isiXhosa heritage) and more recently the Free State (Sotho/Basotho heritage), seeking employment opportunities in proximity to surrounding wine farms and factories (Olsson, 2017) and subsequently, the settlement was formed by illegal squatting. Langrug has experienced flooding disasters, and drug abuse and crime are widespread in the community. Although most residents are considered illegal squatters, basic sanitation needs such as water taps and toilets were provided by the Local Municipality of Stellenbosch (Kenney *et al.*, 2011). Despite the latter, basic services are limited in the settlement with 91 community block toilets of which 83 are functional, suggesting 49 people per toilet. Water taps are limited to 72 people per tap as only 45 are functional (Stellenbosch Municipality, 2011).

***Figure 28**. The informal community of Langrug, divided into three suburbs: Zwelitsha, Nkanini and Mandela Park.*

3.3 The Nature-Based Solution

Aiming to tackle some of these serious issues linked to flooding, stormwater runoff, standing polluted water, linked disease, waste and wastewater disposal, the Genius of SPACE project implemented four solutions in a pilot project in 2016: (1) 27 greywater disposal points were installed to manage greywater run-off, (2) underground wastewater pipes installed to reduce local flood risk and stormwater management, grading and construction of permeable paving improved road surfaces, (3) construction of 15 tree gardens that mimic natural wetlands, filtering water, and (4) the distribution of wheelie bins for the collection and separation of household solid waste (DEADP, 2018), **Figure 29**). The pilot project ended in 2018 and was not continued due to budget constraints, challenges around cooperative governance, unforeseen challenges regarding the ecological infrastructure, communication and integration of efforts between community and local government, and social and institutional issues (DEADP, 2018).

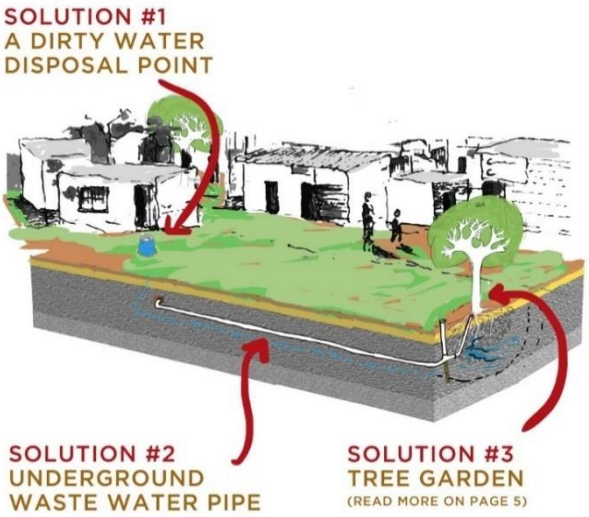


***Figure 29**. The three solutions proposed by the Genius of SPACE project Langrug Community Project.*

4.1 Semi-structured Interviews

The data in this case study were collected and analysed predominantly qualitatively because the research questions demand a holistic approach since the concepts of Nature-Based Solutions (NBS), specifically in the context of peri-urban areas, are broad and difficult to quantify. According to Kapteijns (2020), one cannot merely select some quantifiable elements and subsequently infer things about the entire concept or issues and therefore a qualitative method is better suited for a holistic approach.

The role of actors is a significant feature of NBS because it determines who or what benefits the most. To complete the Lima *et al.* (2020) framework and help understand the perceptions of all stakeholders affected by the NBS, a set of semi-structured interviews was conducted. Two types of stakeholders were considered: implementers (n=10) and community members (i.e. residents and community leaders, n=23), resulting in a total sample size of 33 interviewees. The Research Ethics Committee (REC) at Stellenbosch University approved the interview schedules (**Section 2.3**): ethics number 13114. The interview schedules were developed as part of the NATWiP Research Project, funded by the Water Research Commission (WRC). To establish the practicality of the interview schedule, a pilot study was performed on a sample size of two, an implementer and a community member respectively, whereafter minor edits were made to the interview schedule. The data were collected in two phases: through virtual interviews via Microsoft Teams (implementers) and face-to-face interviews at the Groendal Library (community) which is within a 1 km proximity of the study site. Each face-to-face interview was conducted by a researcher and an enumerator in isiXhosa and recorded for transcription and storage purposes. The data collection was conducted from March to August 2021.

A few community members from the Langrug settlement were approached whose contact details were available through the Genius of SPACE project reporting documents, as well as through implementers and requesting their assistance in identifying a stratified random selection of community members to interview (i.e. varying in age, work situation, home location, etc.) to obtain a range of perspectives. In doing this, we noticed that gatekeeping was taking place in this community, and certain community leaders would identify certain community members. Had we only used one, this may have presented a bias, and therefore we used two community contact points or gatekeepers. Gatekeepers are individuals who are in positions to potentially regulate access to respondents, resources and sites (Hoenig, 2015). Ten implementers were selected in a purposeful way based on the quality of their information on the case study, via a snowball approach, starting with contacts from key publications and reports on the study site and previous projects. The project implementers comprise government officials (regional and local), researchers, engineers, water specialists, and any other contractors who were involved in the implementation phase (**Table 3**).

According to Longhurst (2003), semi-structured interviews are common, informal ways to collect qualitative data. Essentially, it is a verbal interchange between the interviewer who seeks to actively construct data on the respondent's life experiences (Klandermans, 2002). However, what distinguishes semi-structured interviews from standard interviews, is that these proceed in a conversational manner that is flexible and enables participants to elaborate on topics they deem significant (Longhurst, 2003). Similarly, Le Roux *et al.* (2019) states that a wide spectrum of stakeholders allows for one to integrate diverse fields of knowledge and insights on a socio-ecological system and in turn, allows researchers to formulate a holistic understanding of the study of interest whilst avoiding biases. Semi-structured interviews are said to deliver greater depth and breadth of data and create the opportunity to determine the respondents' interpretation of reality, specifically allowing respondents to express their memories and thoughts in their own words (Klandermans, 2002).

Questions were preformulated, however, the probes and conversation differed between interviews. The interviews were based on the novel and flexible methodological framework of Lima *et al.* (2020) which was designed by the NATWiP team to be applied to the international NBS case studies (**Figure 30**). This framework was applied to assess the NBS which is divided into three sections of the NBS implementation process: baseline indicators to assess context, process-based indicators and results-based indicators, as well as a short section to establish baseline information on the person being interviewed. All three indicators were assessed based on the three dimensions of sustainability: environmental, social, and economic. Additionally, the co-benefits related to the NBS were evaluated. Kabisch *et al.* (2016) state that assessing the impacts and associated co-benefits of NBS entails knowledge on health and well-being impacts, environmental performance, stakeholder support, and requires the transferability of results. The semi-structured interviews comprised both open-ended and categorical questions (e.g. Likert scales and binary "yes-no" questions). Notes were made throughout the process – describing thought patterns and justifying decisions made – to ensure the validity of the data (Bennett *et al.*, 2019).

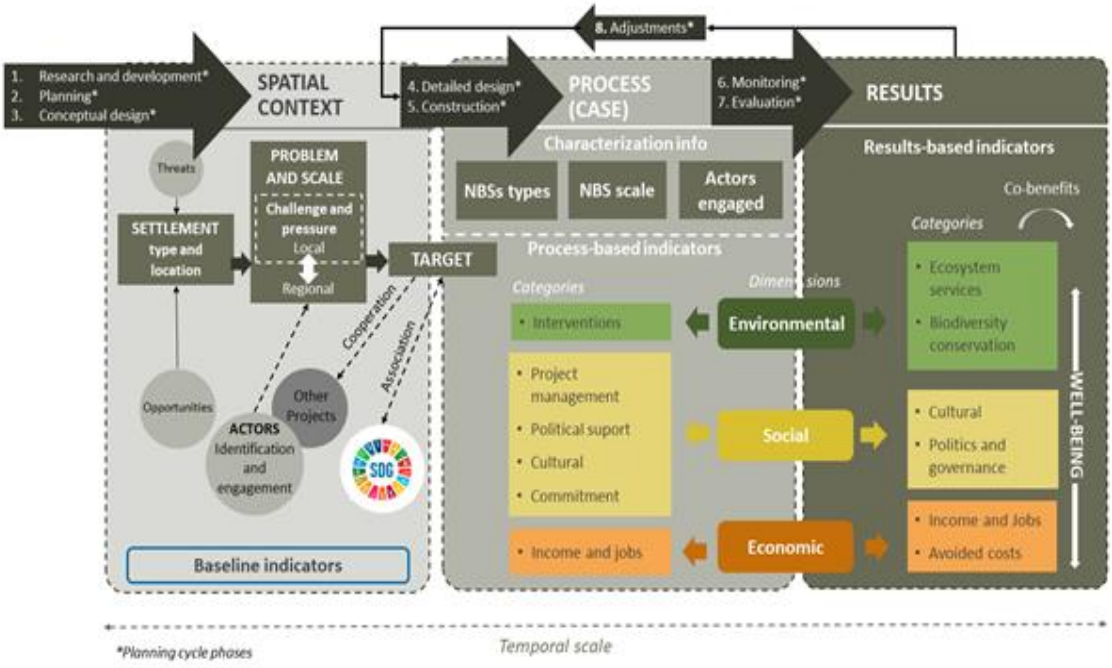


***Figure 30**. The NATWiP Conceptual framework demonstrating how indicators from each of the three sustainability dimensions (social, economic and environmental) were assessed under each of the project phases Lima et al. (2020).*

4.2 Data analysis

Based on this framework, the interviews were translated, transcribed and anonymised and the data were captured in an Excel spreadsheet. A mixed-method approach was used for analysis, where quantitative and qualitative methods were used complementarily. Quantitative data analysis of the categorical questions was performed and qualitative data (i.e. open-ended questions) were coded using an iterative coding method and analysed using Atlas.ti (Braun & Clarke, 2006). Data were coded and thematic analysis (both inductive and deductive) was performed to explore and capture the themes and future trends projected by both stakeholder groups (Kohlbacher, 2006). Inductive coding (open coding) is a method whereby the investigator interprets raw textual data to develop themes and concepts, hence when codes arise from the data also known as a bottom-up coding method

(Thomas, 2006). Deductive coding (concept-driven coding) involves using structure or a predetermined framework (Burnard *et al.*, 2008), where predetermined categories or codes are used and assigned to new qualitative data and is therefore considered a top-down approach (Bennett *et al.*, 2019). Both coding methods were applied as the available literature and framework predetermined many themes and therefore codes were applied deductively, but new themes that became apparent during interviews were coded inductively.

Open-ended questions were mostly analysed qualitatively by thematically categorizing speech, however, the qualitative analysis also included a numeric component where the frequencies of the most commonly mentioned themes were obtained (**Table 4**). Hence, Atlas.ti software mainly assisted with identifying potential themes by reading line-by-line transcripts and these potential themes were arranged based on analytical memos and the frequencies of codes. Murphy *et al.* (2015) state that statistical generalization involves generalizing to populations and similar to experiments, the codes assigned in this case study are aimed to generalize to theories (i.e. analytical generalization). Therefore it is stated that replication is achieved "if two or more cases are shown to support the same theory". Within qualitative analyses, narrative analysis was also performed where interview data such as insightful quotes based on people's realities, were selected to support conclusions, highlight certain themes, and guide discussions (Earthy & Cronin, 2008). Initially and throughout the analysis, immersion was performed via memo writing in Atlas.ti which involves repeatedly looking at the data, forming impressions and making notes with research questions in mind (Bennett *et al.*, 2019). A process known as triangulation was performed, where data obtained from interviews were compared to literature, project reports, and existing interviews (i.e. multiple sources of evidence), which was used for the validity and credibility of results. Essentially, the *constant comparative method* (CCM) was used as a core method to "discover the latent pattern in the participant's words" and is used to identify concepts and group them (Baškarada, 2014). This was done by grouping codes/themes into broader categories/families.

The effectiveness or "success" of the Genius of SPACE solution for water management in peri-urban areas were assessed. Therefore this study discusses the success of the NBS, including the challenges and barriers during implementation. It is noteworthy to mention that "success" creates ambiguity and should therefore be defined. In this study, success was achieved if there was a quantitative improvement when comparing baseline indicators to result-based indicators, or if there was a collective perceived impact detected in interviews qualitatively.

5. Quantitative and Qualitative Results

5.1 Context

Understanding the context assists in better understanding the reality of the community prior to the implementation of the Nature-Based Solution (NBS) in 2016. The results on the context provide a baseline against which to compare the results.

5.1.1 Socio-demographic

Most community members that were interviewed have lived in Langrug for eleven to twenty years (48%) and a large proportion of people have lived there for more than twenty years (43%) suggesting that respondents were well aware of the dynamics and issues within the community (**Figure 31a**). The type of homes the community resides in showed relatively equal proportions (52%, 48%) of backyard dwellings and main houses respectively (**Figure 31b**) of which both home types were predominantly constructed from zinc/corrugated iron sheets (87%).

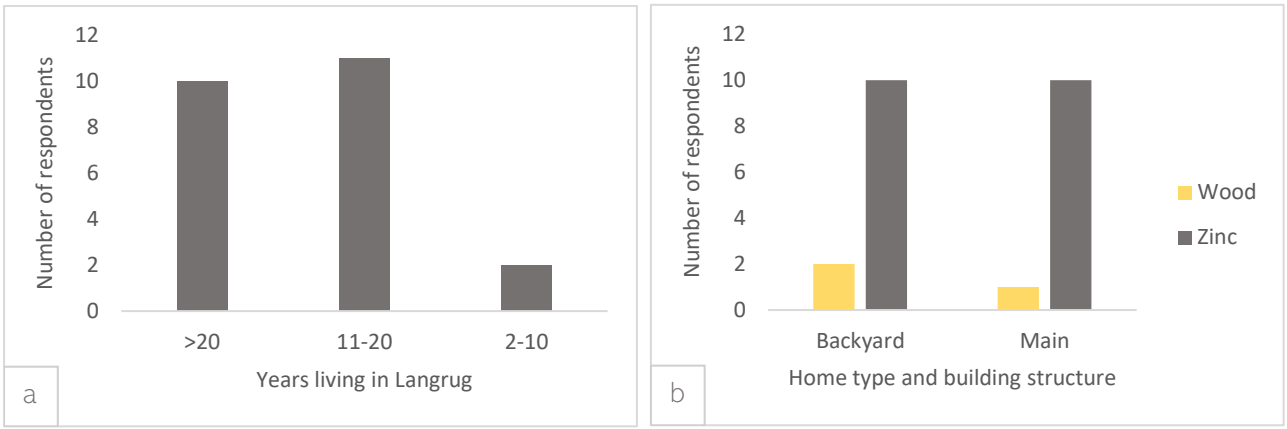


***Figure 31**. (a) An indication of the number of years that the community members lived in Langrug and (b) The home types and building structures used by the community (n=23) Langrug, South Africa.*

Most households in this stakeholder group comprise three people, with a mean and standard error of 3.13 ± 0.28 people and the number of children per household was most often two, with a mean and standard error of 3.19 ± 0.23 children. The age of the household head ranged widely from the youngest at 29 years to the oldest at 72 years, with a mean and standard error of 46 ± 11.50 years. Moreover, genders were represented equally as household heads represented a female: male ratio of 52:48 (**Figure 32a**). Although the community was relatively well serviced, most people walk to collect water from communal taps (91%) and only the community leader had a tap in their house (**Figure 32b**).

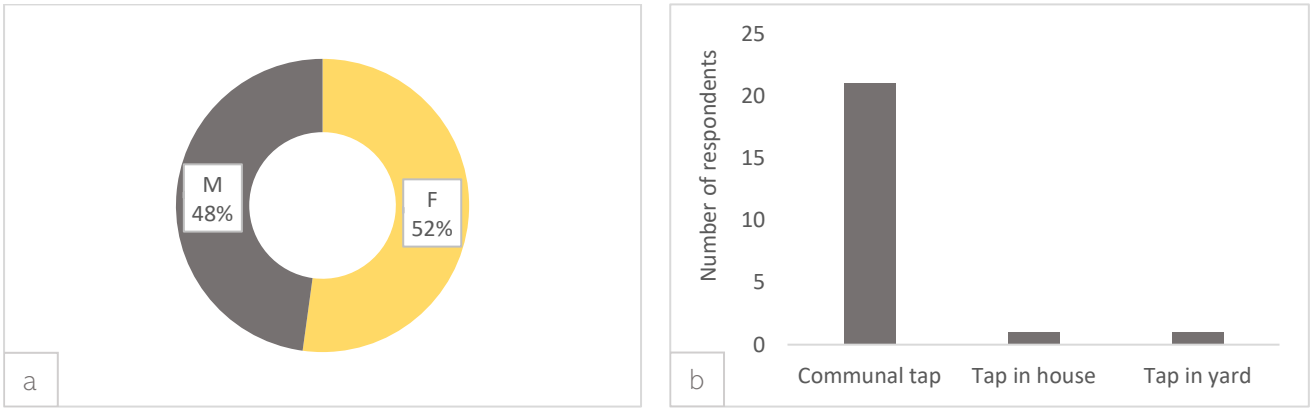


***Figure 32**. (a) Gender of household head according to the community, M is male, and F is female (n=23) and (b) Main source of drinking water of the community members in the informal settlement of Langrug, South Africa (n=23).*

Community members mostly used water for daily household activities such as cleaning, cooking, drinking, and gardening. Before the NBS, the community cited that whoever used the water disposed of it themselves and the main disposal method was to throw it in the streets, on their doorsteps, or in the river streams due to the lack of service provision. Some people had make-shift pipes that were connected to other areas for water to flow there instead of their yards, and some disposed of wastewater at the communal ablution blocks.

> *"Because of the very basic services, that's why people disposed of greywater the way they did." – 10:3 ¶ 9 in I10_Transcription*

Interviews show that Langrug was established on private property and it was mentioned that the laws derived from the constitution state that tenants obtain security of tenure after residing on the property for a certain period. Therefore Langrug ultimately became community-level property or municipal land. The municipality was mandated to provide one toilet for every five families and one water tap within 25 meters per location. This was provided in the form of ablution blocks but because these communal spaces lack ownership, these were often damaged, or components were stolen for personal use (**Figure 33**). Hence, vandalism and theft were pressing issues within the community leaving residents with no privacy and manifesting feelings of unsafety.

***Figure 33**. Vandalized communal toilets with stolen doors (Photo credit: Dandi Kritzinger).*

> *"Most of the toilets are blocked, some don't have doors, or the flush system does not work. We also get water from far (…) We are not given trash bags, so we just throw away trash as is in the main bin which is not collected frequently. Sometimes we get water from a dedicated water truck and the water is brown (…) the communal taps, we find that the tap has been stolen and the water has been running all night." -20:17 ¶ 39 in C9_Transcription*

5.1.2 Implementers/Service providers Information

Implementers' affiliations and roles in the Genius of SPACE project show a diversity of sectors (**Table 3**). Implementers reported that government, civil society, research (academia), citizens and the private sector were all participating actors in the NBS. Interviews showed that the Sustainable Development Goals (SDGs) were not specifically addressed in reports or considered with the onset of the project. However, this project may have started too early to have incorporated the SDGs. Despite this, about half of the implementers cited that the SDGs were indirectly or informally addressed. SDGs that were named by implementers during interviews:

- ✓ SDG 1: No Poverty
- ✓ SGD 6: Clean Water and Sanitation
- ✓ SDG 11: Sustainable Cities and Communities

***Table 3**. General information about the implementers that were interviewed, showing the organization they worked for, the sector of the organizations respectively, and their roles during the implementation phase.*

	Organization	Sector	Role
1	Cape Winelands Biosphere Reserve	Civil society	Assisted with monitoring and involvement with the community in general
2	Greenhouse Systems Development and Informal South	Private Sector	Coordinator of communications and report writing
3	Water Love	Private Sector	Implementation of ecological infrastructure/bioremediation processes (i.e. tree gardens and micro-wetland)
4	Western Cape Government Department of Environmental Affairs and Development Planning	Government (Regional)	Project manager and responsible for the ideation and inception of the NBS
5	Western Cape Government Department of Environmental Affairs and Development Planning	Government (Regional)	Oversight role under the Department of Pollution and Chemical Management
6	Isidima	Private Sector	Involved in the design and development initially and assisted with the implementation (working with the construction team and community)
7	Stellenbosch Municipality	Government (Local)	Oversight role but only joined halfway through the project.
8	Western Cape Government Department of Human Settlements	Government	Representative of the department as a regional town planner and offer guidance to human settlement development
9	University of Cape Town	Academia	Indirectly involved (i.e. research at The Water Hub) and attended stakeholder meetings
10	Western Cape Government	Government	Director: Oversight role over the projects and the implementation of the project

5.1.3 Social

Perception of community health and well-being differed starkly among the two stakeholder groups: 70% of implementers rated health and well-being as “unhealthy”, 20% “very unhealthy” and only 10% “sufficient” (**Figure 34b**) whereas the community, rated health and well-being as “healthy” (35%) and “unhealthy” (35%). While perceptions of the community regarding their own health and well-being ranged widely, no trend was observed for this discrepancy in community member ratings (**Figure 34a**).

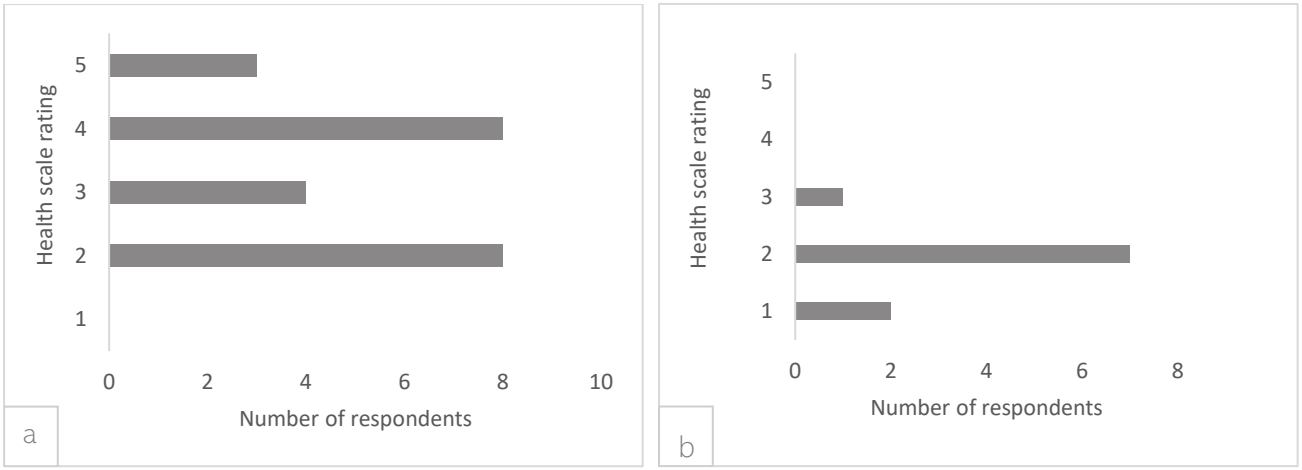


***Figure 34**. (a) An indication of the health and well-being of the community, rated on a scale ranging from 1-5 (one being very unhealthy and five being very healthy) by the community members (n=23) and (b) by the implementers (n=10) Langrug, South Africa.*

> *"No plumbing, no stormwater system or refuse removal. Black and grey water everywhere. The animals and the kids and the rats were used as processing spaces for this accumulation of disease. So the whole community was sick as shown by the water." -3:49 ¶ 10 in I3_Transcription*

According to 90% of the implementers, both women and men had equal access to water before the project. On the other hand, just over half of the community stated that men and women had equal access to water (57%), while approximately 30% of respondents reported that men and women do not have equal access to water (**Figure 35**). Overall, there was some discrepancy between the community and the implementers regarding this question.

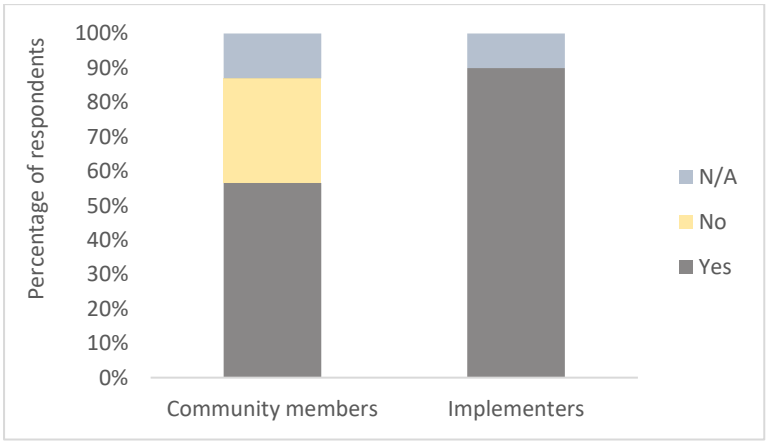


***Figure 35**. An indication of gender equality regarding access to water before the NBS, cited by both community members (n=23) and implementers (n=10) Langrug, South Africa.*

5.1.4 Economic

Economic hardship was widespread in the community of Langrug as indicated by the significantly high unemployment rates. Community members reported that in most households, only one person was employed (43%) or had no employed family member (48%), and in only one household, three or four people had jobs. Of those that were employed, most jobs were casual (26%) or seasonal (17%) and only 4% had permanent employment (**Figure 36** suggesting social vulnerability).

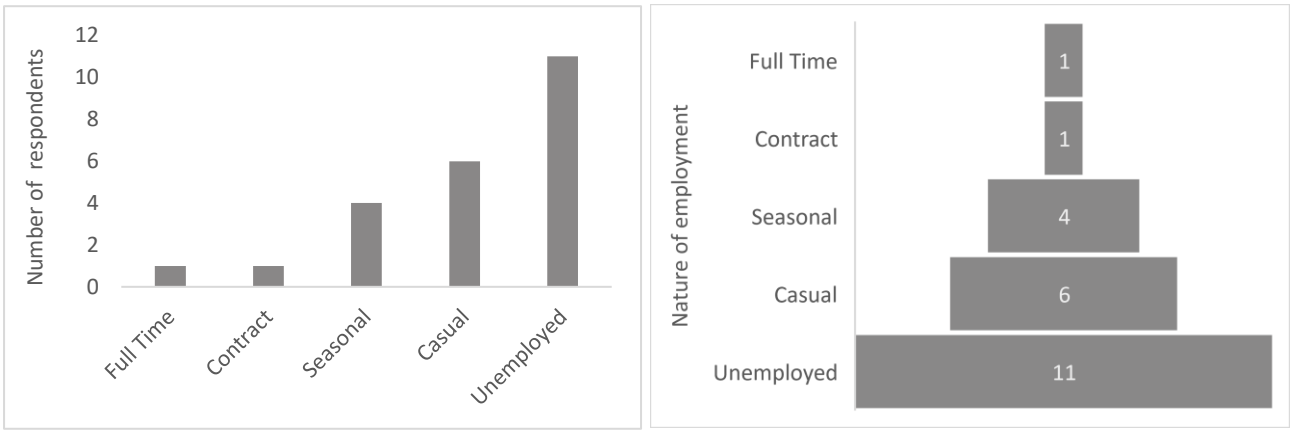


Figure 36. The employment nature of the community according to the residents themselves (n=23) Langrug, South Africa.

Only three community members that were interviewed had a job at the time (**Figure 37a**), and over half of the community members reported that the household head was also considered to be the breadwinner (61%). Implementers rated the economic status of the community before the implementation of the NBS, based on three dimensions: employment, household income and property value. Again, the scale ranged from one to five, one being very low and five being very high (**Figure 37b**). The economic status of the community was rated low, with employment rated low and subsequently household income low to very low. Property values were also cited to be low by most implementers, although, there was some uncertainty regarding this question as property evaluations are not necessarily conducted in the context of informal settlements and therefore half of the implementers did not respond to this question.

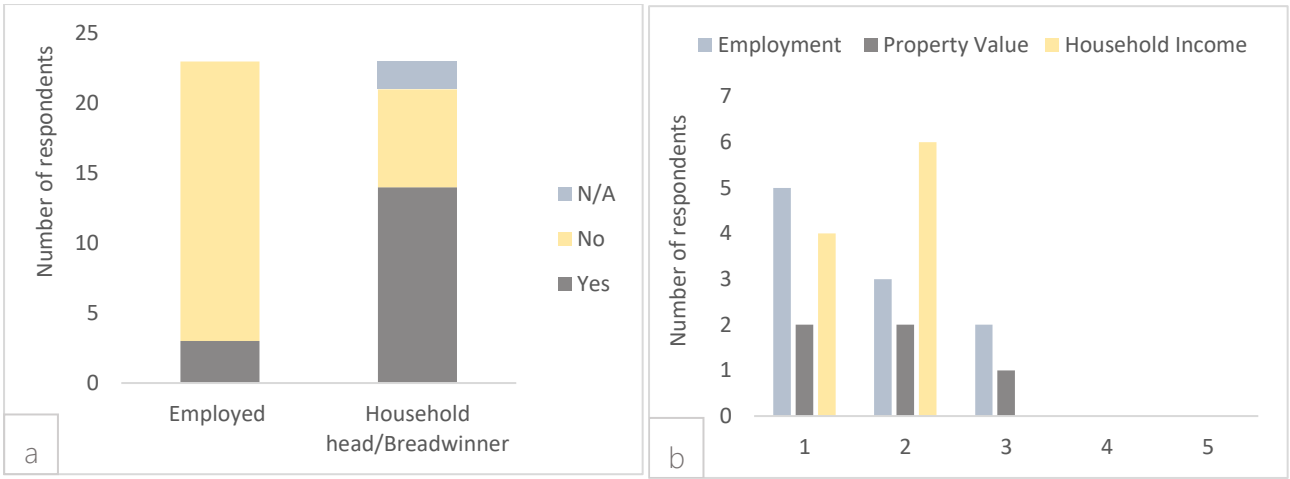


***Figure 37**. (a) An indication of the employment status of respondents during this research study including an indication whether the household head was also the breadwinner (n=23) and (b) The status of the community's employment, property values and household income, reported by the implementers (n=10) on a scale of 1-5, one being very low and five being very high, Langrug, South Africa.*

> *"Some of the socio-economic conditions, in terms of working in a community with high levels of joblessness and low levels of income, the risk that was taken was understood." -4:50 ¶ 46 in I4_Transcription*

According to the community, the informal settlement was relatively well serviced as most respondents cited that they had electricity (91%) and access to water (87%) (**Figure 38**). Furthermore, many community members also had refuse removal services (83%), however, approximately half did not receive sewerage services (57%), highlighting the issue with pollution, eutrophication, and reasons for the initiation of the Genius of SPACE project.

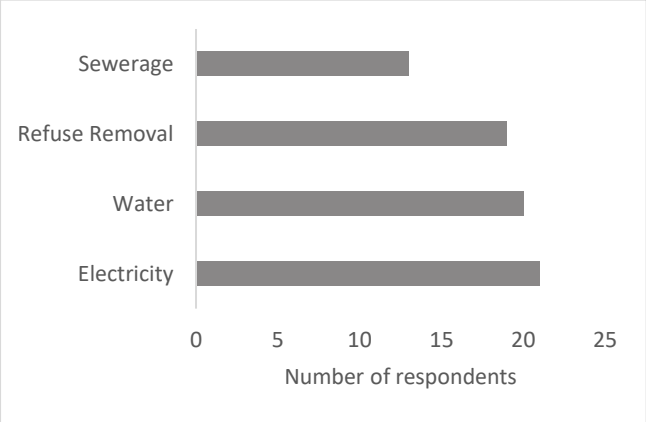


***Figure 38**. Municipal services provided by local authorities as perceived by the community (n=23) Langrug, South Africa.*

Service provision and Town planning

Despite the provisioning of these rudimentary services, stakeholders reported that insufficient basic services substantially contributed to water-related challenges. It is noteworthy to mention that local authorities were struggling to keep pace with the increasing immigration. Logistically, they could not provide sufficient water management services such as a formalized sewer network which resulted in raw sewerage entering the stormwater system and eventually entering surrounding water bodies. It was also cited that existing infrastructure was not maintained and local authorities did not have the resource capacity to manage solid waste in the community. Waste collection services were very basic with a few "skips" containing heaps of accumulated rubbish that was seldomly collected and therefore some community members resorted to littering or burning their rubbish (**Figure 39**). The settlement encroached up the mountain slopes and from an engineering perspective, implementers found it especially challenging to construct drainage systems or any type of infrastructure on such steep locations.

***Figure 39**. Children swinging on rubbish 'skips', Langrug, South Africa (Photo credit: Dandi Kritzinger).*

> *"The amount of houses that we need to build is staggering, we can't keep up with the population growth and because we can't keep up it means our housing list just gets longer and longer as we go along. At this point, it takes 20 years for somebody whose name is on the waiting list to get a house. Imagine you got on the list when you are 25 and now you are 45 when you only get the house. So, you can see the problem is extremely big" -7:25 ¶ 7 in I7_Transcription*

5.1.4 Environmental

Flooding was the most significant water quantity issue as cited by 70% of both community members and implementers and all stakeholders reported that water supply was a challenge in Langrug. More than half of the community (60%) experienced issues around droughts but according to the implementers, drought was not a significant water-related issue in the settlement (**Figure 40a**). Pollution was rated as the biggest water quality issue before the project by both the community (82%) and implementers (90%). Approximately half of the community felt that disease was an issue as opposed to 80% of implementers. Only 17% of the community cited eutrophication to be an issue compared to 70% of implementers, and this may suggest that something is unseen or not directly experienced by the community (eutrophication compared to pollution and disease) is not perceived to be an issue (**Figure 40b**).

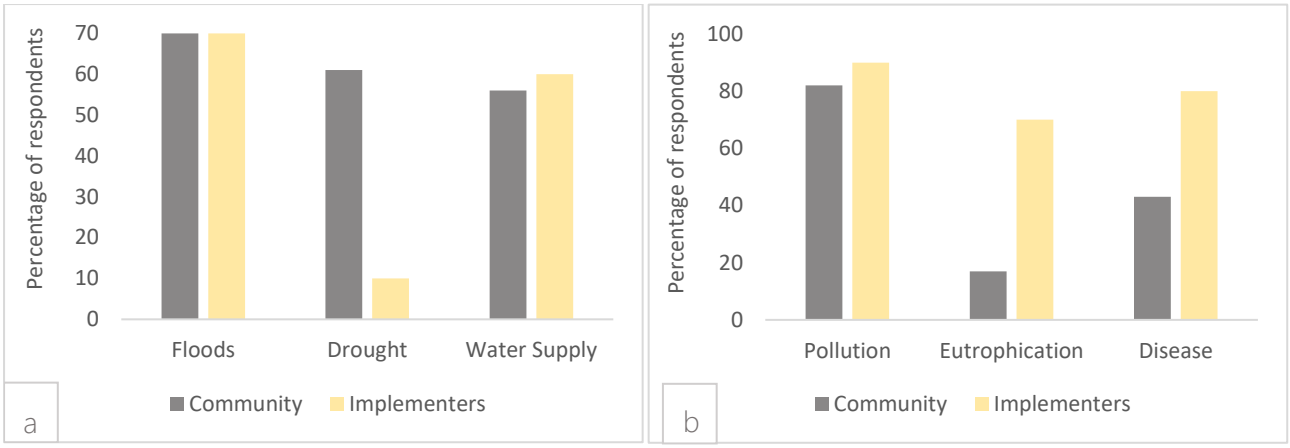


***Figure 40**. (a) Water quantity issues and (b) Water quality issues reported by community members (n=23) and implementers (n=10) Langrug, South Africa.*

Water disposal methods often resulted in water quantity issues as the disposal of greywater and wastewater in walkways, contributed to excess water (polluted by numerous peri-urban activities) in the streets. The volume was amplified by surface hardening which lowered infiltration rates and therefore resulted in pooling of water. Implementers reported that seasonal flooding was a problem – especially since Langrug is located in a minor catchment – and north of the settlement people were carving away an old dam wall to collect soil for various purposes which became unstable and resulted in localised flooding during the winter months. It was mentioned that when it floods the rainwater mixes with the sewage water from the toilets, resulting in high volumes of polluted water flowing through the settlement.

> *"When it rains water flows into my home, and we have to scoop it out with buckets."-19:14 ¶ 39 in C8_Transcription*

Interviews with all stakeholders show that Langrug was muddy, with the pollution that was considered "unpleasant" resulting in poor living conditions for the community. From a community health perspective, water quality issues were addressed by mitigating the impacts of open channels and stagnant pools of dirty water that festered disease. Solid waste was an additional issue and therefore resources were also allocated to the management of solid waste (e.g. a community office area was allocated for sorting recyclables and organic waste).

> *"The Stiebeuel River has a constant E. coli count of at least 6mil units/100 ml which could have caused social and economic hardship because of the exports that are influenced by irrigation. Had they known what was going on with our irrigation water, that would have stopped. That is why the government decided the improvement of Berg River was vital both economically and socially." - 11:3 ¶ 9-10 in I5_Transcription*

A significant proportion of the community cited other water-related issues (83%) to be a challenge such as theft and vandalism of water infrastructure and irresponsible water use (**Figure 41**). Only 35% of the community used nature for recreational purposes or any kind of cultural or spiritual practices before the NBS.

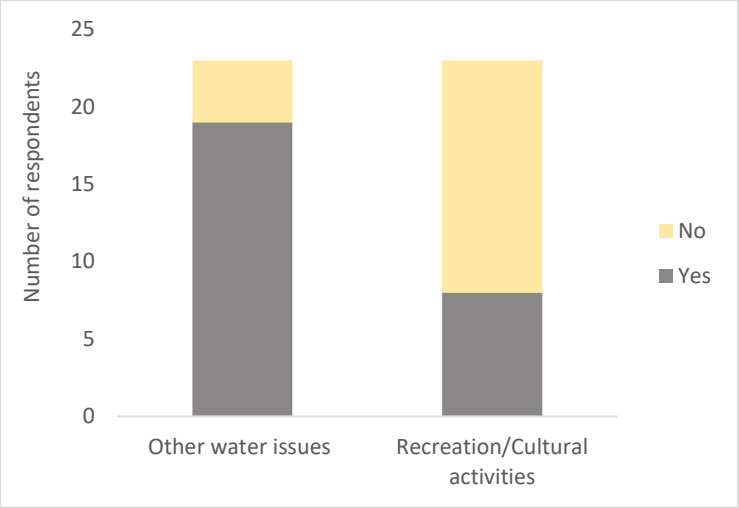


***Figure 41**. A binary indication of other water issues present in the community, accompanied by an indication of residents using nature for recreation or cultural activities before the NBS, according to the residents themselves (n=23) Langrug, South Africa.*

5.2 Process

The process of the implementation of the NBS considers what the situation was like during the construction phase involving the installation of "hard" infrastructure (i.e. tangible or built infrastructure such as the tree gardens and disposal points) and "soft" infrastructure (i.e. intangible infrastructure of human capital such as education and capacity building).

5.2.1 Social

Perceptions of how well the project was run varied. Most community members felt that the project was run well (43%) and overall, 62% of respondents rated it on the upper end of the scale: well to very well run, as opposed to 48% citing the lower end of the scale: poorly run to sufficient project management (**Figure 42**). Therefore it can be deduced that there is some consensus that the process phase of the project was satisfactory according to the community.

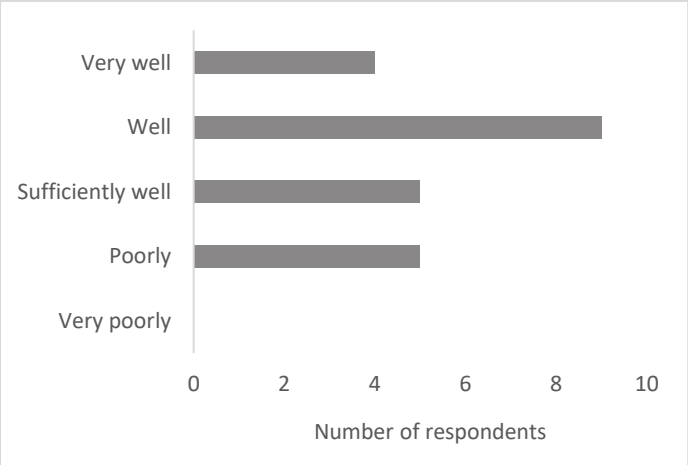


***Figure 42**. Perceived satisfaction with the project management of the NBS according to community members (n=23).*

Scale

Implementer interviews show that the Genius of SPACE project was only a pilot to test the potential of the NBS, but the community wished that the project was upscaled to ensure that the entire settlement had access to the NBS and benefited from it. Implementers found this inequality and disappointment challenging to address because the efficacy of the NBS had to be assessed and the challenges addressed before scaling. Several community members suggested instead of implementing an NBS, more water and sanitation infrastructure should have been installed which acknowledges the fact that informal settlements might not be ideal spaces to experiment with NBS. Following this, the priorities of the NBS were questioned by an implementer as drainage systems such as greywater disposals gained priority over critical issues such as sanitation. It was proposed that a stronger link should have been made between the treatment of greywater and sanitation systems.

> *"In future please listen to the community, listen to their views and implement a strategy that will work for everyone. It must also not end prematurely. When you start something, finish it. I wouldn't say the project made any changes in my section because it didn't serve my section. I would like to ask that if they return they serve all the sections." -22:18 ¶ 34 in C11_Transcription*

Communication

Implementers who actively participated explained that the language barrier between stakeholders was challenging in the early stages but as the involvement from the community expanded the translators became the spokespeople of the process and some implementers could speak the native language which was valuable for effective communication. This "community liaison" – a representative from the implementer's side – acted as a translator ensuring that people understood the process and felt comfortable to participate. Some respondents felt that these differences in language and education were the greatest risks during the implementation of the NBS.

Maintenance

Community members from blocks S&T used the disposal system to dispose of their greywater during the project, however, the drains became congested with litter and some people used it to dispose of blackwater (i.e. sewage) and night soil (i.e. human waste). It was agreed that residents in their respective blocks would clean any solids left on top of the disposal points, but community members were concerned that not everyone in Langrug disposed of water correctly because they were uninformed. It was also agreed upon that the community would maintain wastewater pipes by reporting any bad odours, leakages, and blockages. For the duration of the project, FLOW agents were assigned tasks (i.e. the maintenance crew) who focused on the disposal of water and ensured that there were no blockages. Once the pilot phase ended, trees were also lost to theft and vandalism and the disposal points were left congested because maintenance crews abandoned their responsibilities. Due to a lack of maintenance knowledge, community members often struggled to detect the source of the leakages which resulted in "quick-fix" solutions where the entire intervention was buried in the sand. The community wanted the project to provide them with the required gear and tools to clean the drains and maintain broken infrastructure.

> *"During the project, there was a change but after there was no maintenance and everything went back to the way it was. There was also a bad smell. Some of the filters we installed during the project don't work anymore because of a lack of maintenance." -25:13 ¶ 28 in C14_Transcription*

Almost all implementers (90%) felt that the project was successfully conducted in an interdisciplinary way (**Figure 43**), 80% reported that there was sufficient expertise, skills and knowledge of all the involved actors, and 60% stated that there were technical and/or work environmental challenges (i.e. biophysical knowledge gaps or lack of space). Personal values and attributes surfaced strongly during the project and facilitated the NBS process as reported by 80% of respondents, and 70% felt that there was sufficient and relevant collaboration throughout the Genius of SPACE project. Most implementers (90%) cited that capacity building happened because of the NBS and 70% agreed that cultural or societal values were incorporated into the NBS during the implementation. It is noteworthy to mention that the remainder of respondents were unsure as they potentially had more of an oversight role and therefore were not as involved during the implementation phase. It is evident that power struggles were not necessarily an issue, neither between actors (30%) nor within the community (40%) according to implementers, and signs of conflict or tension among actors during implementation were relatively insignificant (40%) (**Figure 43**). All implementers felt there was joint ownership of the NBS and 80% cited that there was sufficient political support.

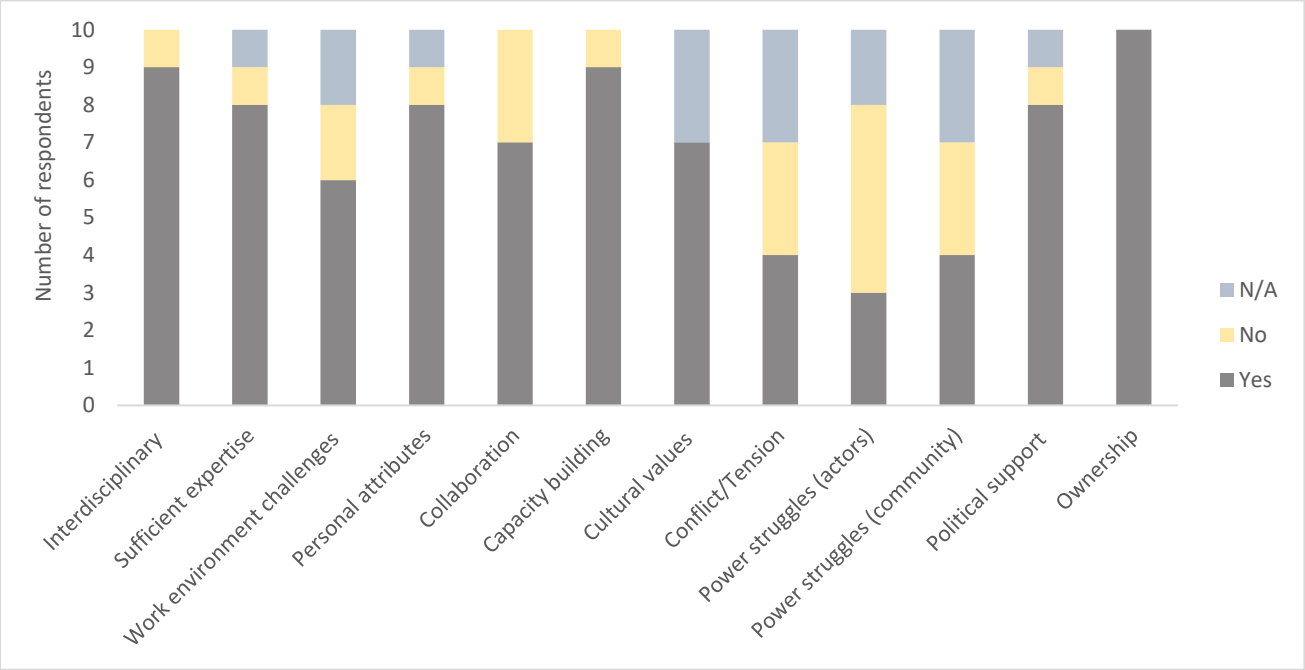


***Figure 43**. Binary (yes-no) answers from implementers based on social dimensions, within the process phase (n=10).*

Sufficient expertise / Work environment challenges

According to implementers, the project was very well run and organized especially in the early stages. It was cited that there was a good understanding of the NBS as a whole; the deliverable potential and the capacity thereof. However, some challenges regarding the implementation phase included the lack of undertaking potential failing scenarios (i.e. contamination of the prototypes, plants not thriving and trees that should have been fenced). Therefore biophysical knowledge gaps included the lack of understanding the upper limits of the indigenous vegetation (i.e. to what extent the vegetation could treat highly contaminated water). A respondent felt that the piloting was insufficient as they hastily started with small-scale construction.

Personal attributes / Capacity building

Implementers reported that during the project they had to be dynamic and flexible as they essentially worked from a mobile office and because they dealt with people's livelihoods it was emotionally draining at times. Nevertheless, the enthusiasm of the involved actors facilitated the process as they

wanted to engage and fight for environmental and social justice. The implementers were involved in workshops before the physical implementation of the NBS - hosting nature walks and there was a lot of investment around understanding what biomimicry was - explaining the ingenuity of nature. Numerous respondents cited a champion saying the commitment, passion, and understanding of this person was key during the implementation of the NBS.

> *"Was fully emotionally and logistically involved so it is hard to step away from that. I think in the end, it became much more about the social level of engagement, rather than the technical aspect (....). The process of what it enabled people to feel… the residents, it gave them something to participate in." -2:44 ¶ 28 in I2_Transcription*

Interviews with all stakeholders show that capacity building and empowerment were prioritized. The community was encouraged to feel comfortable to ask questions and make suggestions. The community was upskilled, and structures were formalized to a greater extent. Formalization was achieved as community members hosted meetings and improved their properties by installing fences and gardens.

> *"There was a lot of capacity building going on. Broadly it was shared between thirty or forty people who were involved in various aspects of community development. Something to be very positive about."-9:17 ¶ 35 in I9_Transcription*

Collaboration

There were low levels of collaboration between the regional government departments involved which included the Solid Waste Management Department, the Department of Water and Sanitation, the Department of Transport and Public Works, and the Department of Environmental Affairs and Development Planning. This may have been due to a turnover of government officials during the project, resulting in a loss of momentum. There were appreciable collaboration attempts between the community, the technical team, and the provincial government, however, sustained involvement from the local government was lacking. Although initially there was active participation from local authorities and they attended numerous meetings, this commitment also fizzled out which may have been due to the interdisciplinarity of the NBS. In addition to the various regional government departments involved, a committee was established within the community – the Langrug Community Project Committee (LCPC) that was formed as a representation of the community and comprised community leaders and ward committee members – who actively participated in meetings and were key drivers of the project. This resulted in numerous meetings for which local authorities did not have the capacity at the time.

> *"We had meetings with them, but I think that's probably where the failures took place, we couldn't keep up with the amount of meetings (…) needed more meetings within different groupings within the community and we couldn't. There wasn't sufficient time to do that."-7:33 ¶ 73 in I7_Transcription*

Community members expected higher levels of collaboration, they wanted to be consulted before the ideation of the project and wish they had the opportunity to voice what they deemed important issues in Langrug. Almost all actors agreed that the implementation of the NBS was an integration of bottom-up and top-down methods: initiated top-down and driven bottom-up. Although it was not implemented as bottom-up as originally intended, implementers spent almost two years to ensure that the input from the community was recognised. There was some uncertainty as the community did not fully understand that the NBS was intended to serve them and they were rather adamant to receive services and expected RDP (Reconstruction and Development Programme) houses. Therefore the community expected a top-down approach but with the onset of the project, they gained a greater understanding of the NBS and started leading the process.

> *"I called the counsellor, which is the Deputy Mayor. Then I said, come here. Remember one thing. You are not the bosses of the community. You are servants of the community." -37:15 ¶ 88 in C11_Transcription*

Conflict / Power struggles

Interviews show that sources of conflict among the community were generally related to the lack of basic services and feelings of jealousy around employment opportunities which ultimately resulted in a lack of support from the community. Tension was detected regarding work ethics, contracting, financial compensation, and conflict arose due to theft and vandalism. To get involved in projects as such, community members must consult the community leaders and ward committee. Several community members reported that it was beneficial to have community leaders present as they were good conductors. It was mentioned that the Langrug community specifically had leadership potential warranting trust, communication and connections within the community which essentially contributed to the selection of Langrug for implementing the NBS. Although the emerging leaders in Langrug contributed to high levels of the capacity building during the implementation phase, there was some disagreement whether this leadership was genuine. Some respondents felt that the community leaders truly represented the interests of the community and that power struggles were generally absent. However, others felt that there were power struggles especially around those that were politically orientated or felt that leaders wanted to be recognized by improving their status which may have been interpreted as personal agendas by the community. The interviews show that some leaders personally benefited more from the NBS than other community members.

> *"Given just the nature and dynamics of that community and the various players involved, pretty certain there were power struggles with the community themselves i.t.o of some key members of the community trying to ensure that they were the legitimate leadership and a constant battle around that." -4:48 ¶ 36 in I4_Transcription*

This was contextualized by a respondent: Approximately 6 000 people live in Langrug, with the collective low-income areas of Langrug, Groendal, and Mooiwater amounting to nearly 7 800 residents, and the entire valley of Franschhoek comprise approximately 17 000 residents. The respondent highlighted this "balance tip" – the densest populations were encountered in low-income, peri-urban environments – therefore it is plausible that community members experienced feelings of animosity and anger when there were signs of community leaders personally benefiting from the NBS.

"I would like to let you know that there are people who always come here, telling us that they are here to help our community only to find out that they just came here to pretend to the executives so they can spend the money allocated to the project on themselves. Even some of our community members are to blame for such criminal activity. We would prefer that the project executives notice what is happening and come up with an alternate plan such as asking the community what they would like the money allocated to the project to be spent on." -16:14 ¶ 28 in C5__Transcription

5.2.2 Economic

There was some disagreement on costs that were supported for the duration of the implementation phase which can be attributed to the fact that some stakeholders were not involved with the financial aspects of the project. Despite this, 60% felt that personnel costs were supported, half cited that maintenance and communication were supported respectively, and only 40% said that participatory processes were financially supported. All implementers stated that the main funder was public and 90% felt the project funding was unsustainable and short-term (**Figure 44**) and only 40% of implementers reported that private investment was encouraged.

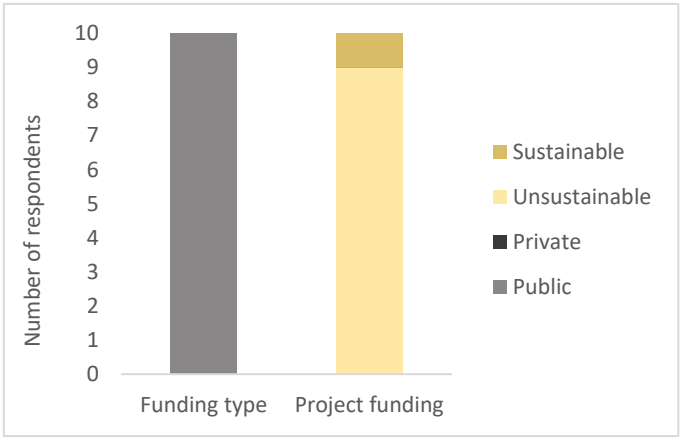


***Figure 44**. Binary answers by implementers on the type of funding obtained and the sustainability of financial resources for implementing the NBS (n=10).*

Funding

Essentially stakeholders struggled to find a self-sustaining solution to improve the water quality while upholding the NBS with the ongoing funding arrangement. With NBS in peri-urban contexts, the physical implementation of infrastructure is proceeded by numerous meetings, consultations with the community leaders and collaborating with local authorities to establish an action plan. It was cited that community involvement requires a lot of administration and negotiation (80%), whereas the actual physical construction and implementation roughly amount to 20% of the effort and resources. Therefore it was suggested that a significant percentage of the financial resources are allocated to "soft" infrastructure interventions.

"There was a lot of effort that went into establishing links between the community and collaboration. And that is often a difficult task, it takes time, and you spend money and in a normal sense you can't show much, show I built this, I've done that. But it is a very important investment, a lot of effort went into that."-10:13 ¶ 27 in I10_Transcription

There was disagreement among implementers regarding attempts made to attract private investment. During the initial stages, there was no success to attract private investors which were due to complex rules and regulations around the private sector industry. Efforts to encourage private investment were low due to the lack of capacity at the time and attempts to attract the hospitality industry was mostly around crowd-funding campaigns that were linked to existing environmental NGO initiatives. Additionally, non-monetary investments included making connections between the community and the recycling industry. Stakeholders felt that general public awareness was lacking and that more effort should have gone into approaching local organizations and neighbouring farmers. Numerous marketing attempts and communication campaigns were released but were mostly unsuccessful possibly due to a lack of understanding of the potential and benefits of the NBS. It was mentioned that the NBS may have contributed to indirect avoided costs i.t.o. the risks related to water quality and water treatment (i.e. costs saved by reducing pollution and in turn, securing water supply). From a social perspective, avoided health costs were linked to improved water quality but implementers felt that the local government missed the opportunity to embrace the NBS and benefit from it, especially with the potential of reduced costs. An additional funding challenge was mentioned by an implementer: "Because people living in informal settlements do not pay taxes, the government has to cross-subsidise between communities." It was mentioned that the higher income classes are becoming poorer leading to an economic collapse and resulting in insufficient funds for infrastructure provisioning and they felt that this is a massive stumbling block for funding mechanisms. Another respondent stated that provincial and regional governments were experiencing budget limitations that will only become more severe in the future.

> *"Two elements of the project and second one never took off, so the income generation side never happened. If phase two was implemented there would have been funding to sustain maintenance."-6:17 ¶ 46 in I6_Transcription*

5.2.3 Environmental

About half of the implementers (60%) confirmed the construction of the interventions mentioned in Section 3.3 but generally, there was uncertainty regarding the interventions that were ultimately established in Langrug, which again may point to differing degrees of involvement in the Genius of SPACE project. The vertical wetland was meant to be established on a nearby school field but was never installed and downscaled eco-machines. These eco-machines were established downstream at the Water Hub site and comprised shipping containers with compartmentalized plants serving as small wetlands to filter greywater emanating from Langrug. The Water Hub was another intervention in the area – found at the old Franschhoek wastewater treatment works – which was a demonstration facility for NBS type technologies. The idea was that some of the water discharged from Langrug would be diverted to the wastewater sewerage works and the remainder treated using these eco-machines. This purified water would have then been reused by the community.

Stakeholders perceived the construction of the permeable paving as the most successful intervention of the NBS (**Figure 45**). It was cited that the area adjacent to this permeable paving was much cleaner as it prevented the pooling of water by improving local infiltration and reducing bad odours. Others mentioned that the pavement distributed water efficiently when it rained and prevented soil erosion. Therefore this intervention was considered a success, having direct environmental impacts (i.e. reducing water quality and quantity issues) and indirect social impacts (i.e. improved water quality resulting in improved health).

"Nice to see that road at least is a safer, cleaner space." -6:21 ¶ 56 in I6_Transcription

***Figure 45**. (a) An existing greywater disposal point in a walkway, also showing structures in Langrug that are typically constructed of corrugated iron sheets, and (b) An improved road surface with permeable paving for stormwater management in March 2021 (Photo credit: Karen Esler).*

5.3 Results

5.3.1 Social

The majority, 74% and 70% of community members and implementers respectively, cited an improvement in health and well-being following the NBS. The community's access to water for daily use did not significantly improve after the NBS, as 35% of the community and a mere 20% of the implementers cited an improvement. The community cited an improvement in gender equality regarding water access (65%) whereas none of the implementers cited this improvement. According to community members, water became available for alternative uses after the NBS (83%), which is in contrast with the implementer's views as only 30% answered yes to this question. Both stakeholder groups felt that the NBS did not shape the way the community used nature or natural resources for recreation with only 10% of the implementers and 43% of the community citing this behaviour change. There was some consensus regarding cultural values as 50% of the implementers and 43% of the community agreed that the NBS shaped the cultural values and practices of the community (**Figure 46a-b**).

About half of both stakeholder groups felt that the NBS affected the environmental identity (i.e. how connected people are to nature) of the community. A significant percentage of the community (78%)

reported an improved social cohesion (i.e. connectedness, sense of community) after the Genius of SPACE project and all implementers agreed there was good participation from the community. According to the community, there were no perceived changes in crime following the NBS but the project fulfilled an educational role: 83% of the community reported being more aware of what happened to wastewater (**Figure 46a**). Few implementers felt that policies were formalized as a result of the NBS, and less than half of the implementers cited that the lack of legislation around the NBS was an issue (**Figure 46b**).

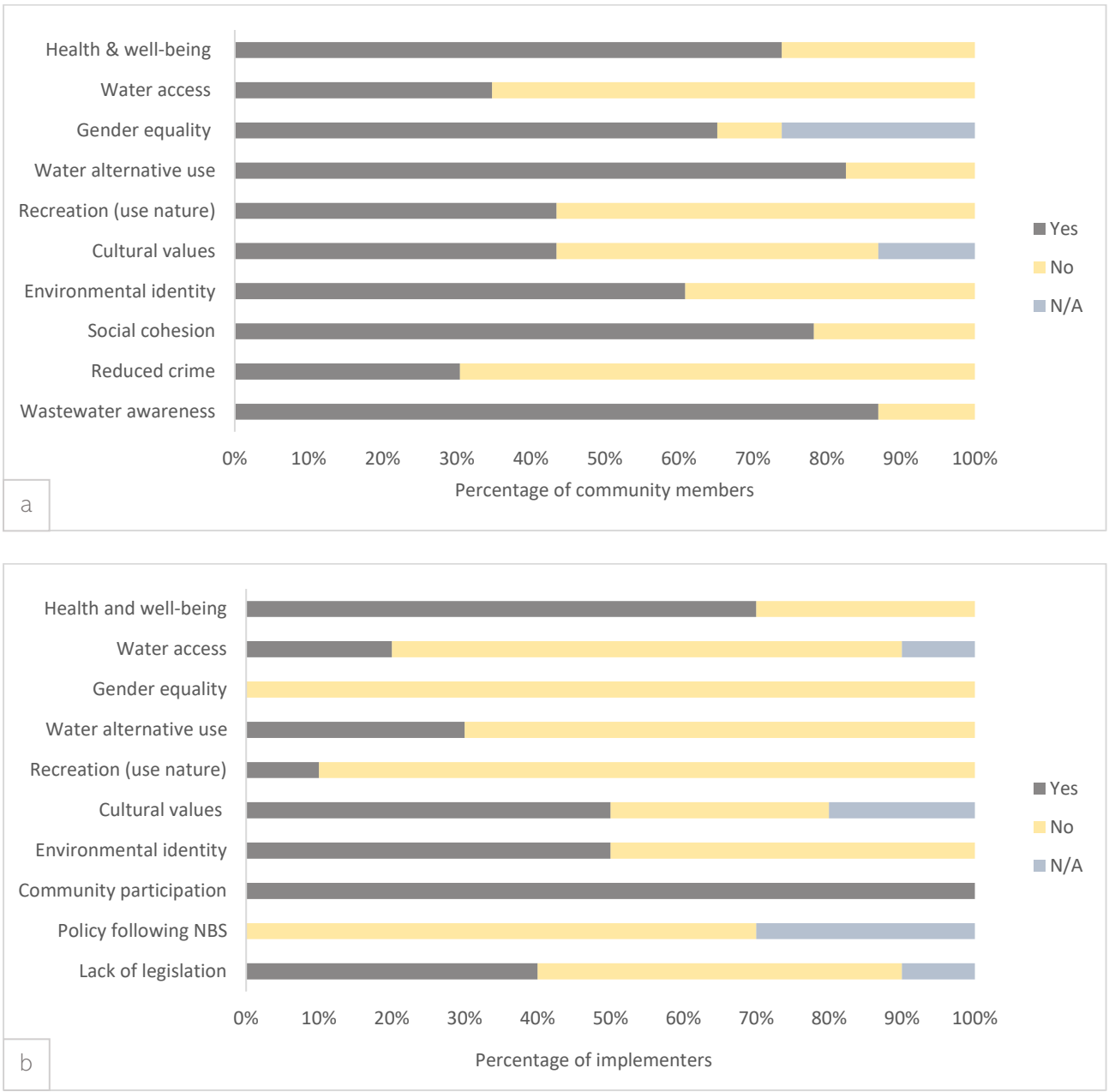


***Figure 46**. (a) Binary (yes-no) answers from the community (n=23) and (b) The implementers (n=10) based on social dimensions, within the results phase.*

Health and well-being

Stakeholders cited that there was some improvement in community health, but it was unclear to what degree (**Figure 47**). Socio-economic impacts were perceived anecdotally and indirectly as respondents felt that fewer community members were becoming ill and in turn, fewer people missed out on

employment opportunities. An implementer who specifically worked with the microbiome interventions reported that after the NBS people's skins were healing. Scientific evidence regarding health improvements was lacking overall, but most stakeholders agreed that the installed infrastructure contributed to the health and well-being of the community. Only two implementers cited hard evidence of which one reported a measurable reduction in *E. coli* levels during the NBS. Contrastingly, another implementer mentioned that the water quality was analysed monthly and detected *E. coli* levels were just as high as before the NBS.

> *"We were horrified to see the water flowing from the sanitation systems that were failing very badly, flowing through the crèche. At one point, the children were swinging above water that was of very low quality. Also, near the school field, the water of very poor quality was accumulating as well as solid litter."-9:3 ¶ 9 in I9_Transcription*

***Figure 47**. Water disposed of in the streets resulting in polluted water flowing down the street, festering disease (Photo credit: Dandi Kritzinger).*

Water access / Water alternative use

Although water access was not specifically addressed by the Genius of SPACE project, it was cited numerous times (**Table 4** in Section 5.3.5) specifically in community interviews. There were no perceived issues regarding water access for residents that lived near the ablution blocks, but most people walked long distances to collect water of which some walked up to thirty minutes and waited in queues. Therefore they requested improved access to communal taps. It was a safety hazard walking long distances to utilize the toilets or to dispose of wastewater after dawn, resulting in irresponsible water disposal. Although the NBS was not geared to improve access to water, it did contribute to more water becoming available for alternative uses. The community started piping water that was used to run washing machines which potentially generated income and most of the community used the extra water for their vegetable gardens.

> *"The water is too far from my house (…) So, my recommendation is always that let people recommend the closest place where you can locate the tap stands or even the toilet facilities*

because at night there are 'skollies', or there are boys who stand on the road, and you know, they can rob you, they can rape somebody. So, I think for me, if your stomach is running at night, you will have a problem. Individual taps, I think this is something that we could work on, or maybe cluster." -37:9 ¶ 78 in C11_Transcription

Environmental identity

Implementers cited a definite improvement in environmental awareness of the community, specifically in the piloted area. After the NBS there was a much greater appreciation for the environment and community members supported this, saying they were more conscious of reusing water and keeping their areas clean. One implementer felt that the project broadened the horizons of those who actively participated; the community grew very fond of their gardens and the project exposed them to the potential of agriculture.

"Many people walked away with a much better understanding of the environment and the impact that everyone has on it and the role and responsibility that individuals have in maintaining their own environment and the larger environment of the municipality." -8:14 ¶ 41 in I8_Transcription

Wastewater awareness

After the project, there was a much better understanding of the disposal of water. The community educated each other on wastewater disposal and some taught themselves to build pipelines due to the impact of the project. Implementers hoped that this understanding would permeate throughout the entire informal settlement and that the obtained values were not diluted because of the high turnover of people in peri-urban environments. As Langrug comprise many recent arrivals, it created a mentality amongst residents that the settlement was only a temporary home and therefore the degradation of the environment and infrastructure was not a priority for them. According to implementers, there was still some use of the greywater disposals after the NBS which worked to an extent, but essentially it only channelled the greywater, leading to the stormwater channel and ultimately into the Stiebeuel River.

"We did our own disposals. Thanks to the project, we were educated and trained on how to create these disposals." - 27:20 ¶ 53 in C16_Transcription

Recreation / Cultural attributes / Social cohesion

It was perceived that the NBS had a minor impact on recreational use although numerous members considered gardening, which was initiated by the project, a recreational activity. This had cultural significance as the medicinal herbs were mostly indigenous to the Eastern Cape but efforts made to incorporate the community's cultural values into the NBS typically failed to make an impact after the project. All respondents perceived high levels of social cohesion, especially in the early stages.

"One man, (…) who loved his plants. So, he was also always contributing. We would make food, make home remedies and cleaning stuff, all those basic skills." -3:23 ¶ 37 in I3_Transcription

Community participation

There were low levels of engagement from the community during the early stages and implementers underestimated the willingness of the community to confidently engage. Community participation was encouraged through the distribution of a community newspaper, pamphlets, door-to-door knocking with translators and meetings were announced over loud-speakers, and meetings and open days were held. This commitment deteriorated towards the end of the project, especially since there was no financial reward for maintenance crews. One implementer emphasised that lack of community participation was a major constraint during the implementation phase, reporting that usually only 50% of the public participates and that this lack of community engagement was ultimately a bigger constraint than lack of funding because a constant investment is required to motivate the community.

> *"We were very insensitive to the community's capacity and capability to kind of understand these things, so once we invested the time for them to understand what this meant and how you should do it, the process and protocol to follow and what this all requires got better but it was probably too late at that point."-4:36 ¶ 81 in I4_Transcription*

Policy / Legislation

Implementers felt in the context of the global south, South Africa is generally quite progressive with innovative interventions as such and although there were no set policies, the environmental legislation of the country is enabling and quite strictly enforced. Despite this, most respondents mentioned that any type of legislation would have had a minor impact on implementing the NBS especially since there were no human resources to enforce written documents. The aim was rather to use the NBS as a demonstration for similar scenarios and to make an argument that these types of solutions are efficient and generate several co-benefits. The principle learnings of the Genus of SPACE project have been used as a demonstration for NBS in Villiersdorp and Nkanini, Stellenbosch. Although no official policies were developed by the local government, the DEADP generated a process flow to address the issues associated with the NBS. It was cited that in the context of informal settlements, there are generally issues around policy and legislation regarding the implementation of services.

> *"Not intended to inform policy, a demonstration project and to support a more widespread role out of this." -6:3 ¶ 11-13 in I6_Transcription*

5.3.2 Economic

Based on responses from both stakeholder groups, there was no perceived improvement in property values following the NBS (**Figure 48**). All implementers cited that the NBS created new jobs for the duration of the project, and this was supported by 78% of the community themselves. Consequently, the community perceived an improvement in household income, however, the implementers felt that the few employment opportunities created failed to significantly contribute to any expectation for improvement in household income. More than half of implementers (60%) felt that the project created jobs indirectly (e.g. through tourism) and 60% reported other economic benefits such as avoided costs due to the NBS.

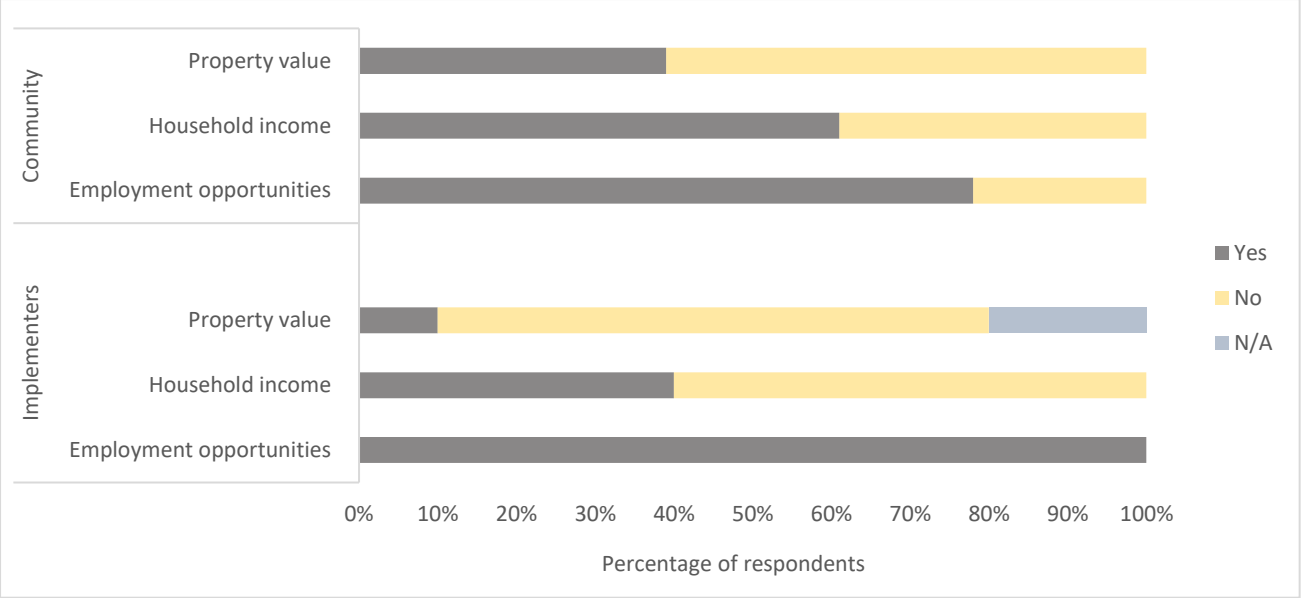


***Figure 48**. Binary (yes-no) answers by both stakeholder groups based on economic dimensions within the results phase.*

Direct employment opportunities

Numerous community members reported that the high crime levels experienced in Langrug were largely attributed to the lack of employment opportunities. Therefore there was a hyper-focus on local community employment and a construction team was employed for nine months who rotated with other members of the community to ensure a shared community impact. A small-scale agricultural initiative was to be established around the eco-machines to support the community economically and ecologically. Water purified by the NBS was meant to be used for growing vegetables to be sold at a profit and contribute to a circular economy. An implementer contextualized the economic impact saying that in a community of approximately 20 000 people only 10-20 people were regularly involved, the project made a minor impact in terms of job creation. It was mentioned that with these kinds of initiatives, the community must earn an income from the early stages of the project when behaviour changes are vital and amendable.

> *"We would like to get more job opportunities, by cleaning the area (…) My additional comments include that I wish the project can resume and be implemented in all of Langrug."* - ***26:22 ¶ 50 in C15_Transcription***

Indirect employment opportunities

The community leveraged funding indirectly through activities such as tourism because the project created some visitor interest. During the pilot phase, there were guides stationed at the entrance of Langrug who took groups on site visits. Community leaders benefited from secondary funding opportunities, although not directly from the project itself. One implementer reported that they aimed to create tourism opportunities as part of the Berg River Improvement Plan (BRIP) called the Berg River Camino where tours were meant to start at the upper catchment, moving downstream, linking initiatives such as the Genius of SPACE project. This opportunity was never realised due to challenges such as safety concerns and lack of support from private landowners because they were reluctant to allow people on their land.

"Main stumbling block, it could only happen for as long as there was funding and needed a way of generating money to keep it running. The ideas were there, selling herbs, doing tours. But the ideas didn't get put in reality."-2:49 ¶ 52 in I2_Transcription

5.3.3 Environmental

Overall, respondents reported that aesthetic services (73%), as well as water purification services (61%), showed the most significant improvements (**Figure 49**). Evaluating feedback from the two stakeholder groups independently, there was some consensus that the implementers mostly perceived improvements in cultural/aesthetic services, particularly aesthetic services (90%), science and education (80%), and recreation (70%), whereas community members mostly perceived improvements in regulating services: water purification and regulation (61%) respectively, soil quality regulation and retention (57%) respectively, and air quality regulation (57%).

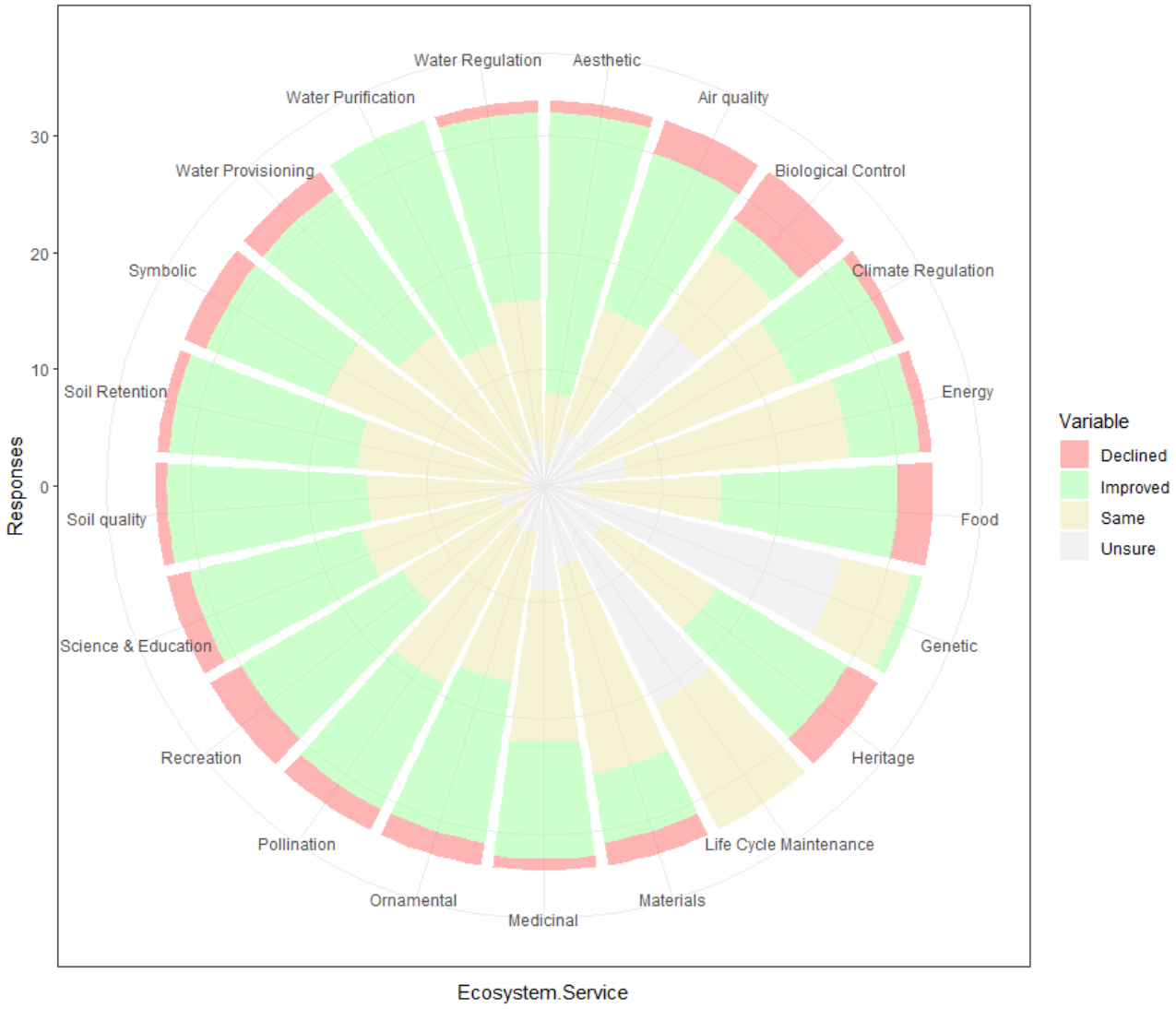


***Figure 49**. The perceived impact of the Genius of SPACE nature-based solutions on ecosystem services according to implementers and community members (n=33).*

5.3.4 Challenges to implementation

Implementers ranked their three most important challenges during the implementation phase which directly relates to our second research question. According to the implementers, the greatest challenges were sustainable funding (60%), social imbalance (50%), and stakeholder support (40%). Additional challenges that were deemed important by the implementers can be seen in **Figure 50**.

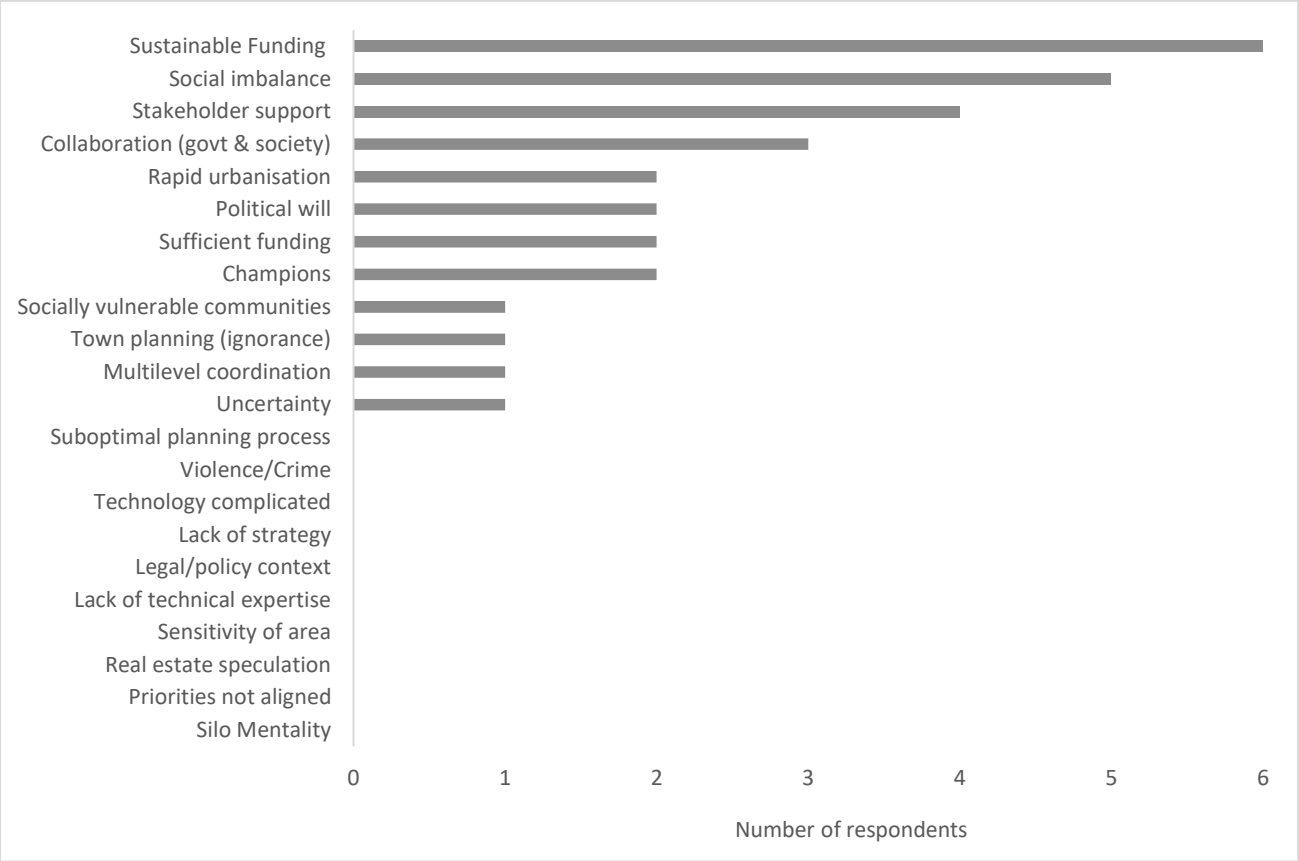


***Figure 50**. Key NATWiP project meetings and workshops from 2020-2021.*

5.3.5 Thematic Analysis

The coded interviews in Atlas.ti show that the codes/themes with the five highest frequencies were: water quality (n=60), water disposal (n=59), water access (n=58), services (n=56), and employment opportunities (n=47). Thus, these themes were mentioned most frequently by all stakeholders. **Table 4** shows a total of 80 codes/themes which were further grouped into categories (i.e. code-families) of nine, used to guide qualitative analysis. The themes were colour-coded according to the incidence of code frequencies, ranging from low frequencies (red) to high frequencies (green) to visually display the frequencies of themes mentioned during interviews. The incidence of the code-families/categories (i.e. accumulated code frequencies) was unevenly spread. Although water-related themes obtained the highest frequencies, the category with the most citations were social (n=273) highlighting that major patterns in interviews were socially orientated, followed by infrastructure/services (n=263). Code-families with the fewest codes were legislation/politics (n=86) followed by involvement/participation (n=87). It is noteworthy to mention that the high incidence of code-families based on social indicators may be due to biases in the interview schedule because environmental indicators were predominantly quantitative.

***Table 4**. Summary of frequencies of codes/themes within each category/family.*

Category	Theme	Frequency	Category	Theme	Frequency
Environment	Pollution reduced	21	Economic	Avoided cost	7
	Pollution river	22		Funding type	12
	Environment polluted	23		Tourism	12
	Pollution solid waste	24		Funding challenge	12
	Environmental awareness	27		Unemployment	13
	Gardens	33		Funding investment	14
Water	Water use irresponsible	10		Funding unsustainable	20
	Water alternative use	17		Unsustainable unemployment	26
	Water quantity	17		Employment opportunities	47
	Water use	29	Project management	Silo's	5
	Water access	61		Monitoring	6
	Water disposal	62		Champion	6
	Water quality	63		Town planning	8
Infrastructure/Services	Infrastructure grey	7		Interdisciplinary	10
	Population growth	9		Unforseen challenges	11
	Infrastructure permeable paving	11		Innovation	12
	Demonstration NBS	12		Knowledge gaps	12
	Ownership property	13		Communication	14
	Water Hub	15		Dissapointment	16
	Ownership infrastructure	16		Scale	23
	Infrastructure green	21		Informal settlement complication	29
	Maintenance	24		Unsustainable project	31
	Nature-Based Solutions	24		Project management	35
	Infrastructure soft	25		Collaboration	35
	Sanitation	27	Involvement/Participation	Participation implementers	7
	Services	59		Participation public	11
Social	Security	9		Participation academia	11
	Social imbalance	11		Political support	13
	Cultural attributes	12		Participation government	16
	Formalization	13		Participation community	29
	Environmental Identity	14	Conflict/Power struggles	Power struggles	11
	Social cohesion	15		Community leaders	15
	Empowerment	16		Politics community	15
	Prosperity	18		Conflict	22
	Recreation	19		Crime	41
	Personal attributes	20	Legislation/Politics	Legislation	11
	Education	21		Politics community	15
	Equality	21		Policy	18
	Capacity building	43		Community procedure	19
	Health & well-being	41		Local authorities	23

6. Discussion

This case study aimed to evaluate the success of the Genius of SPACE project based on a sustainability framework, including the identification of barriers and challenges experienced during implementation. This allows decision-makers to evaluate the impact of nature-based initiatives to possibly facilitate socio-economic-policy alterations to overcome these challenges or to adopt the opportunities. The pilot project showed potential to address both biodiversity and societal challenges in the peri-urban. However, the results show that budgetary constraints and complex social and institutional issues hindered the upscaling of the Nature-Based-Solution (NBS) and therefore the piloting of NBS in peri-urban spaces was ultimately questioned.

6.1 Challenges/barriers and socio-economic-policy recommendations

The challenges experienced during the implementation of the project addresses our second research question. These barriers are concurrently discussed with socio-economic-policy and governance

contexts that would favour the implementation of these NBS projects in the peri-urban spaces, addressing our third aim.

Communication and stakeholder fatigue

Community members were disappointed that their concerns were not voiced which hinders the adoption of bottom-up approaches and discourage the use of interventions (Davies *et al.*, 2019). Numerous peri-urban residents feel that there is limited social inclusion during decision-making processes related to NBS. This may have been due to language barriers which made the community feel excluded from the development planning processes (Thorn *et al.*, 2021). The lack of good communication strategies for community engagement may result in a mismatch between urban plans and local needs, creating feelings of antagonism towards authorities which is enhanced by notions of the colonial past (Hossain *et al.*, 2018). Actors must be sensitive when approaching communities as some peri-urban spaces are overstudied, as with Langrug, creating a sense of mistrust between citizens and decision-makers. There has been a mistrust between the community and local authorities which may have contributed to this lack of support from the local government, highlighting why sound relationships are required for the co-production of knowledge and ultimately the transfer of knowledge (Thorn *et al.*, 2021). To overcome this, a balance between political and technical voices are required which enhances the validity of information shared (O'Donnell *et al.*, 2017). Personal spheres of transformation are required to develop relational and cognitive qualities to cope with the increasing diversity and complexity of novel governance (Brink *et al.*, 2018). These qualities influence how government officials develop relationships with civil society, negotiate and relate to each other, address conflict, analyse data, develop policy, and make decisions (Wamsler & Raggers, 2018).

Service provision and challenging working spaces

A continuous influx of people complicated the planning of the NBS as local authorities could not cope with the additional volume of greywater, which resulted in a polluted environment. Conventional stormwater management approaches in peri-urban areas are unsustainable, resulting in degradation of the environment, frequent flooding and human health issues (Lundqvist, 2021). Traditional drainage systems divert water from the streets to a water treatment plant but when heavy precipitation is experienced these rigid systems can only handle a fixed capacity, resulting in flooding or overflows of untreated sewage and stormwater (Zhou, 2014). Causal mechanisms that increase stormwater runoff such as reductions in infiltration and imperviousness exacerbated floods in the settlement (Kabisch *et al.*, 2016). Nature-based interventions provide opportunities to achieve peri-urban resilience as these interventions are buffered against natural fluxes, especially in the face of climate change where varying water quantities create uncertainties (Wendling *et al.*, 2018), and potentially also against human-induced inconsistencies.

Lack of space was a constraint during the implementation (**Figure 51**), which is generally an issue working in peri-urban environments (Krauze & Wagner, 2019). Therefore issues around town planning were a barrier for the construction team, especially since there was some uncertainty from the local authorities regarding the way forward given what was implemented during the project, and NBS require more space and time than traditional grey infrastructure solutions (Pontee *et al.*, 2016). Most legal frameworks with the potential to scale NBS implementation are conflictual with peri-urban areas or outdated and scattered (Sarabi *et al.*, 2019). This is also attributed to the legacy effects of apartheid where certain urban policies remain influenced by the history of the country in the sense that access to green spaces is influenced by spatial segregation (Davies *et al.*, 2019). In the context of the global south, outdated policies and regulations usually result in inefficient urban planning that does not promote NBS (Roy *et al.*, 2018).

***Figure 51**. Rubbish accumulating in a small wetland within the densely populated settlement where land is scarce (Photo credit: Cape Winelands Biosphere Reserve).*

The formalization of the entire settlement was mentioned, however, this is concerning because as soon formalization proceeds, areas get reinvaded which underscores this "wicked" problem in peri-urban spaces that are characterised by dynamic and challenging working environments (Folke *et al.*, 2005). Governments tend to continue to work within these constraints as they resort to known, "rigid" methods as opposed to more "risky" adaptive management approaches and as a result, they struggle to cope with the rapid urbanization rates (Roy *et al.*, 2018). Rigid government institutional structures and the lack of forward-looking strategies prevents NBS mainstreaming (Pasquini & Enqvist, 2019). Municipalities are generally reluctant to integrate NBS with infrastructure upgrading initiatives because of perceived inflated capital costs, historical preferences, and low return on investment (Sarabi *et al.*, 2019). This is often considered a cognitive barrier as decision-makers make decisions based on past experiences and are reluctant to alter these decision-making processes due to pro-grey infrastructure path-dependence (Sarabi *et al.*, 2019). This change of practices is hindered by a lack of integrated management across scales both vertically (from national to local) and horizontally (inter-agency coordination) (O'Donnell *et al.*, 2017). It is therefore advised that training programs on NBS are upscaled and that educational efforts are equal to grey infrastructure. As shown in this case study, there is usually some dependency on grey infrastructure. Water purification functions or the provision of flood protection in peri-urban spaces with high densities could not be achieved by solely implementing ecological infrastructure (Davies *et al.*, 2019).

Institutional capacity and collaboration

The interdisciplinarity of the project discouraged government involvement and generally, stakeholders of NBS such as government departments operate in institutional fragments (i.e. sectoral silos) where respective departments have unique procedures and visions (Spires *et al.*, 2014). This limited cooperation within and between institutions, and across the urban governance domain

becomes especially challenging when managing NBS due to its interdisciplinary nature (Lindley *et al.*, 2018). It is proposed that collaboration efforts are enhanced across different sectors, and the holistic nature of the NBS creates the potential to overcome these institutional silos by creating multifunctional spaces (Pauleit *et al.*, 2017). It is also advised that internal cooperation and working structures are altered and that existing capacities are tapped into to ensure longitudinal integration of NBS (Wamsler *et al.*, 2020). Moreover, efforts must be made to preserve existing knowledge and to distribute knowledge across respective government departments when there is a turnover in staff (Carter *et al.*, 2015). There is very little existing policy support for this type of NBS in South Africa but even when appropriate legislation and policies exist, enforcement capacity and implementation can limit the establishment of NBS (Dhakal & Chevalier, 2016).

Ownership, responsibilities and paternalism barriers

Due to financial limitations, the community offered human resources which ultimately contributed to the community-owned infrastructure ideation of the project. Building trust between the community, local authorities and the technical team is vital to overcome socio-cultural barriers (Shackleton & Njwaxu, 2021). If the community understand the value of the NBS and if they actively engage in the design and implementation they are more inclined to invest their limited financial or human resources to maintain the intervention (Pasquini & Enqvist, 2019). However, this was generally not achieved by the end of the project because community members demanded financial rewards and regarded service delivery as the government's responsibility. This "paternalism barrier" suggest that communities often revoke individual responsibility and view it as the responsibility of authorities which leads to uncooperative attitudes and a lack of commitment to maintain NBS (Mensah, 2014). The paternalism mentality of some community members (i.e. those unwilling to pay for basic services but prepared to pay for non-essential goods) constrain the implementation of NBS. Furthermore, those regarding their homes as temporary or those who anticipate eviction are less likely to improve their property value (Thorn *et al.*, 2021). In peri-urban environments, dynamics related to ownership rights constrain community incentives to improve NBS and this also complicates monitoring (du Toit *et al.*, 2018). It is therefore recommended that simplified, accelerated land tenure reforms are implemented to allow low-income groups to enter the property market and obtain some degree of ownership which improves attitudes and responsibilities towards the surrounding environment (Davies *et al.*, 2019).

Funding challenges and conflict

The NBS was considered a failure based on economic dimensions as employment opportunities were minor and temporary and sustainable funding was a fundamental barrier for implementing the project (**Figure 50**). If the project team was incapable of spending the allocated budget within a certain period, the opportunity to get a similar budget diminished due to the level of competition for financial resources across government departments. This created a sense of urgency to spend the funds and deliver on project objectives as opposed to working thoroughly, incrementally and attaching a level of quality control to the deliverables. Therefore government-led funding mechanisms were very short-term, cyclical and punitive (Frantzeskaki *et al.*, 2017). Benefits derived from NBS generally only become apparent over longer temporal scales which hampers their acceptance by decision-makers with short-term goals and deliverables (Albert *et al.*, 2019). This is specifically challenging in the context of informal settlements as it is a tedious process to build trust within communities and usually when the funding diminishes, trust from the community also weakens. Limited funds from local authorities create barriers for NBS and therefore it calls for alternative economic opportunities and private sector contributions (Van Ham & Klimmek, 2017).

Limited buy-in and lack of communication from local authorities created conflict at times and conflict between regional and local authorities were also detected, which may be due to confusion over who should operate and maintain NBS projects in the long term which is caused by unclear institutional

mandates (Titz & Chiotha, 2019). There were also concerns regarding effective budget management and quality control deliveries. In the global south, the absence of transparent financial management of public spaces is a barrier for implementing NBS and conservation plans are often constraint by political interference and mismanagement of financial resources even when there are enabling national policies and regulatory systems for urban development (Muderere, 2011). Moreover, corruption tends to be more severe in peri-urban spaces because of lower levels of transparency and accountability (Nuhu & Mpambije, 2017).

Maintenance, monitoring and public involvement

Testing and evaluating the performance of the impact NBS was lacking as only water quality data of rivers downstream were collected. A common barrier to scaling NBS is a lack of data availability including design and performance data (Thorn *et al.*, 2021). The lack of evidence-based data (i.e. the effectiveness of the NBS over various temporal and spatial scales), as well as the dearth of wide-ranging information regarding the NBS, may create significant uncertainty especially among the public or result in conflict among stakeholders (Krauze & Wagner, 2019). Thus, it is proposed that data gathering methods are rigorous in future pilot projects which requires the necessary processes and tools to track and monitor NBS, and efforts can be increased by involving citizens and scientists (Wamsler *et al.*, 2020).

Despite the lack of financial incentives to support maintenance after the project, long term maintenance is generally poor in peri-urban environments as interventions are often contaminated and serve as areas to hide criminal activity (Wamsler *et al.*, 2020). Therefore logistical challenges such as safety issues and in turn, access to sites would have been a barrier in maintaining and monitoring the NBS in Langrug. Knowledge diffusion was a barrier during the pilot phase as the understanding of the NBS was mostly grasped by experts and academics, resulting in low levels of acceptance by the public (Santoro *et al.*, 2019). Although attempts were made to obtain private signatures and connections within the Franschhoek community to generate funds that would circulate back to the community, it was mostly unsuccessful. It is proposed that public engagement be enhanced by improving awareness of the benefits and costs of the NBS (Van Rensburg & Tortajada, 2021). The Water Hub shows potential to enhance public awareness as it takes on the role of an urban living lab initiative. Universities can act as knowledge brokers by facilitating such initiatives and involving private sector actors, authorities, residents, and other relevant actors to collectively implement solutions (Davies & Swilling, 2018).

Social imbalances contributing to implications for conservation

The social vulnerability of the community is depicted visually where high unemployment rates and few sustainable employment opportunities are compared to Maslow's 'Hierarchy of Needs' (**Figure 52**). Maslow's hierarchy suggests that survival relies on physiological, safety and social needs whereas psychological survival depends on self-esteem and self-actualization needs (Nunes *et al.*, 2016). In this study, high crime rates and security issues indicate that the safety needs of the community were not met and basic needs such as water and food were marginally met, suggesting the lowest level of Maslow's hierarchy was the reality for most community members. Therefore it is plausible that support from the community was lacking at times because "when all needs are unsatisfied, humans are dominated by physiological needs, and all other needs are pushed in the background" (Datta, 2008). When the basic needs of citizens are not met, it is unlikely that they will engage in sustainability efforts. To gain environmental consciousness, a level of self-actualization (e.g. self-fulfillment that can lead to a new focus of caring for the environment) must be achieved.

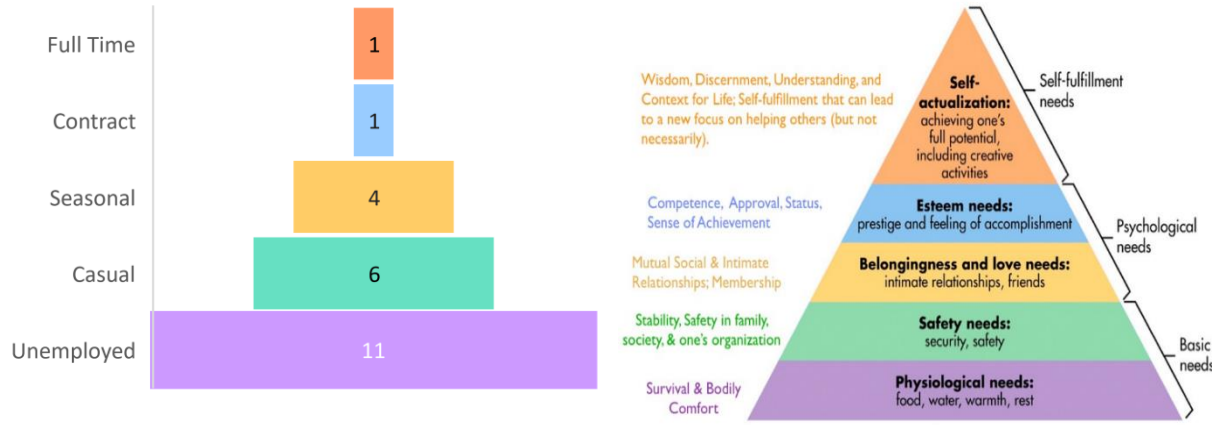


***Figure 52**. Social imbalances represented by associating the employment statuses of the community to the Maslow's Hierarchy of Needs signifying the pyramid nature of both schematics.*

South Africa is characterized by its heterogeneity both physically (i.e. rugged topography and rich biodiversity) and culturally (i.e. diverse cultures and varying socio-economic groups). This was also indicated by the differences in perceptions among the two stakeholder groups throughout the study. Although this diversity contributes to the resilience of socio-ecological systems, it also creates vulnerabilities and implications for conservation. Social imbalances and therefore varying perceptions and priorities amongst stakeholders create uncertainties and complexities for sustainable development (Wendling *et al.*, 2018). The global south is subject to existing vulnerabilities such as rapid population growth which will only be exacerbated by climate change, leading to implications for communities in peri-urban environments as they are disproportionally affected by these shocks and disturbances (Bele *et al.*, 2014). Marginalized and disenfranchised communities are at greater risk of extreme events and associated water challenges caused by climate change (Moser & Ekstrom, 2010). Although the higher-income groups are impacted, they have the capacity to withstand these pressures. Following this, the piloting of NBS in the context of informal settlements was questioned. Acknowledging that health and productivity are crucial in peri-urban environments, it was questioned whether a temporary, small-scale community project was appropriate for testing the efficacy and success of an NBS. Implementing NBS with limited financial resources, especially when the interventions require long-term maintenance was bound to fail. It was therefore proposed that NBS piloting should rather be performed in higher-income areas where the pilot group has the capacity to deal with the consequences and challenges of a failed system. Although environmental and social connections were enhanced, implementers recognized the challenge in doing this, due to the multiple socio-economic challenges faced in peri-urban contexts, creating uncertainties (Kabisch *et al.*, 2016).

6.2 Success and opportunities of the NBS

The first aim of this case study was to evaluate the success of the NBS based on sustainability indicators. The NBS was mostly successful based on social indicators, as the intervention improved the health and well-being of the community, played an important role in education, and enhanced social cohesion. By reducing pollution and providing water and sanitation infrastructure there are benefits for public health (Wolch *et al.*, 2014). The installed intervention was somewhat successful in cleaning the environment for the duration of the pilot phase (noting that evidence was mostly anecdotal and rigorous data was lacking) and delivered great benefits in terms of ecosystem service provision.

Capacity building and social transformation

Social targets were achieved because there was a large focus on co-design and co-creation and the project was targeted towards the community by offering support and establishing a sort of governance

structure for them to manage and maintain. The value of including local knowledge does not only revolve around engaging the community in the delivery but also harnessing their knowledge about these systems for the delivery of the NBS in its specific context (Ramírez-Agudelo *et al.*, 2020). Furthermore, the benefit of community buy-in to NBS is that it strengthens residents economically and politically (Pasquini & Enqvist, 2019). There is often a perception that funds are wasted if it is not spent on physical infrastructure, although with this project, the team managed to install the physical infrastructure while upskilling the community simultaneously. The project enhanced ecological awareness, suggesting there was some advancement up the hierarchy of needs. Therefore it is perceived that NBS in peri-urban spaces creates the potential for improved environmental consciousness which can lead to improved conservation efforts. The co-benefits generated by the NBS may help fulfil physiological needs (e.g. water purification and food provisioning benefits) of the community. Hence, advancement up the hierarchy of needs is expected, making people are more inclined to adopt NBS interventions. In a sense, NBS with the associated co-benefits catalyses a positive feedback loop building a case for mainstreaming NBS.

Innovation, prosperity and socio-economic opportunities

The interdisciplinary nature of the project was key during the implementation of the NBS as it resulted in a broad array of expertise and skillsets to address the challenges. These types of solutions have greater impacts than conventional grey infrastructure systems and affect additional stakeholders that would have otherwise not had the opportunity (Somarakis *et al.*, 2019). Numerous stakeholders expressed strong feelings of accomplishment during the pilot phase; the community could grow resources and kept themselves stimulated with the allocated opportunities. When plants were thriving, and the infrastructure was functional there was a sense of prosperity in Langrug and the community would like the project to be reinitiated. Despite the challenges faced, implementers acknowledged that the project was the first of its kind suggesting there was a lot of improvisions, highlighting that adaptive management is key for such projects. For the NBS to be sustainable, it needed to be implemented through a process of integration and scale, starting small and slowly building the relevant knowledge and understanding, and therefore involving multiple stakeholders in due course to ensure confidence (Wamsler *et al.*, 2020). Following the project, there was a large focus to start implementing NBS and to acknowledge "green" infrastructure as equal to "grey" infrastructure (Lundqvist, 2021). To ensure that NBS are included in development plans, it must be considered on the same par as grey infrastructure - especially in the global south - "green" and "grey" infrastructure show remarkable potential as a hybrid intervention (Staddon *et al.*, 2018). These hybrid solutions incorporate engineered systems with nature-based approaches resulting in an optimal solution regarding space requirements, cost expenditures and environmental impacts (Santiago, 2016). The Genius of SPACE project demonstrated that green-grey integration shows potential to decrease the risk of pollution diffusion to downstream rivers and minimize flood risk while generating co-benefits (Davis & Naumann, 2017) such as improved health and well-being.

Private investment and partnerships

Involving the private markets can be effective because certain carbon markets provide incentives not only for the carbon-related benefits but also for environmental, social, and economic co-benefits. This is particularly advantageous for upscaling NBS that addresses both societal and biodiversity challenges (Wendling *et al.*, 2018). It is therefore proposed that NBS are implemented through the private sector as opposed to grant-based funding that depends on the public sector and its complex government structures (Droste *et al.*, 2017). The use of economic incentives can be an enabler as it encourages stakeholders to adopt NBS and therefore accelerates interest and action; these financial models can potentially inform and accelerate policy development (Van der Jagt *et al.*, 2017). International commitments (e.g. Vision 2030 with related Sustainable Development Goals 6, 11, 13, and 15) creates room for novel funding mechanisms especially considering inequalities manifested by historical legacies (Venter *et al.*, 2020). It was suggested the funding model include the formal areas of

Franschhoek that can afford to pay for services and in turn, potentially show investment interest in the improvement of surrounding rivers. Giombini & Thorn (2021) also propose that upstream and downstream linkages between low-income and high-income neighbourhoods are disentangled and that the higher income groups contribute funds more actively to advocate and ensure that benefits related to the NBS are shared by all citizens.

Partnerships with local stakeholders are vital to promote education and facilitate ecosystem stewardship to build resilient socio-ecological systems (Van Ham & Klimmek, 2017). Moreover, partnerships between enterprises and other urban stakeholders must be formed to show the economic and social worth of NBS and to lessen reliance on the public sector (Sarabi *et al.*, 2019). The public sector lack funding for long term maintenance (e.g. upkeep of ecological infrastructure) and fail to acknowledge the benefits delivered over longer temporal scales (e.g. delivery of ecosystem services)(Thorn *et al.*, 2021). This suggests that monetary and non-monetary valuation of NBS must also be upscaled to improve the appreciation of natural capital and drive funding mechanisms (Wangai *et al.*, 2016). Public-private partnerships are required to facilitate direct and indirect financial investments and can demonstrate that NBS complement existing infrastructure making it more attractive for investments while reducing risks (Staddon *et al.*, 2018). These partnerships are advised as they integrate the flexibility of the private sector (i.e. expertise and funding) with the public sector (i.e. top-down regulation) (Eggermont *et al.*, 2015).

7. Conclusion

The most challenging barriers for implementing this particular NBS were associated with socio-economic constraints (i.e. sustainable funding and social imbalances) contributing to lack of stakeholder support. It was proposed that future projects apportion their budget for 80% community engagement and 20% for the physical NBS implementation work. This is considered extreme, underpinning why informal settlements are possibly unfeasible locations to pilot NBS, despite being vitally necessary for these environments. Evaluating the efficacy of NBS in higher-income areas creates greater potential for financial models to shift from a rigid, siloed public sector to a flexible, multi-disciplinary private sector, and financial investments can potentially drive policy. Funding mechanisms regarding NBS are complex and ultimately individuals will take the financial responsibility on themselves with a trade-off of a minor economic “sacrifice” but a return of substantial social benefits. By experimenting with NBS in higher-income areas where residents can invest in the intervention, there is also the potential for enhanced stakeholder support. Following the idea of Maslow’s Hierarchy of Needs, higher-income communities have likely reached a level of self-actualization, suggesting there is potential for citizen science contributing to extensive monitoring required for NBS.

Although peri-urban spaces are partially selected because they occur in transition zones, space constraints in informal settlements paradoxically hinder implementation. These interventions could first be piloted in the outer suburbs (e.g. estate-type neighbourhoods characterized by low-density housing and open green spaces) and implemented in peri-urban spaces once it meets the deliverables. However, this comes with the trade-off of losing social benefits (e.g. social transformation) and disregards the unique circumstances in peri-urban spaces that drive NBS and therefore create an opportunity for further investigation. Intact policies are required for effective coordination to promote the understanding and value of NBS and therefore focus efforts to restore and protect natural infrastructure. Despite the lack of demonstration projects to inform policy, water-management challenges can serve as a proxy to build a case for mainstreaming NBS. Long term investments and collaborative efforts among multiple stakeholders including experts with scientific backgrounds to monitor interventions efficiently and to detect knowledge gaps are required. The scarcity of data on NBS underscores the need to generate evidence-based data to improve maintenance, quantify costs, performance, and ecological benefits in a standardized manner to drive the acceptance of NBS and consider it an equal solution to conventional practices. These solutions require larger spatial and

temporal scales to show their potential for securing high-quality water and delivering co-benefits that also occur over varying spatial and temporal scales.

3.1.2 Guiding long-term restoration of riparian ecosystems degraded by plant invasions in peri-urban areas: Insights from South Africa

Abstract

Restoring riparian ecosystems in human-dominated landscapes requires attention to complexity, and consideration of diverse drivers, social actors, and contexts. This study uses a mixed-method approach, integrating historical data, remote sensing techniques and stakeholder perceptions, to guide restoration of a river in the Western Cape, South Africa. An analysis of aerial photographs of the riparian zone from 1953 to 2016 revealed that although anthropogenic land conversion happened primarily before the 1950s, several land use and land cover classes showed marked increases in area, including: waterbodies (+1074%), urban areas (+316%), alien weeds (+311%) and terrestrial alien trees (79%). These changes have likely been driven by land fragmentation, changes to the hydrological regime, disturbance, and agricultural intensification. Stakeholder interviews revealed that despite the clear need for restoration, several barriers exist to successful implementation; these stem from inadequate financial resources, inappropriate funding models, institutional challenges, and a lack of techno-scientific knowledge. We give several recommendations to overcome these barriers.

Introduction

Rivers and riparian zones are often associated with human activity due to their water provisioning services (Richardson *et al.*, 2007). As a result, these systems are degraded by human-mediated disturbances such as water abstraction, damming, land use changes, and recreational activities (Zelnik *et al.*, 2020). Direct impacts of such disturbances facilitate invasion of alien plants, some of which out-compete and replace native species due to their ability to rapidly colonize disturbed areas and change the microclimate of invaded patches (Stella *et al.*, 2013). Invasive alien trees in riparian zones significantly reduce streamflow and surface runoff (Richardson *et al.*, 2007), alter water quality (Galatowitsch and Richardson, 2004), cause significant loss of biodiversity (Sala *et al.*, 2000) and diminish the capacity of these ecosystems to deliver key services (Guida-Johnson and Zuleta, 2017).

Alien tree invasions thus severely threaten the biodiversity and integrity of riparian systems, with feedbacks to the economy and the well-being of society (Dufour *et al.*, 2011). In South Africa, degradation of ecosystem services results in direct economic losses, with the agricultural sector being impacted most heavily, followed by tourism, and water supply (Blignaut and Aronson, 2020). Invading alien plants currently reduce water yield by 38 million m^3 per annum in the water-scarce Western Cape Province of South Africa (Le Maitre *et al.*, 2019). To prevent further water losses, clearing of invasive stands has been proposed as a control mechanism. As the clearing of invasive species is often considered an action or intervention intended to promote the recovery of an ecosystem, it can be considered a restoration activity (SER, 2004).

Ground surveys are the traditional method used to collect data for planning and monitoring restoration projects (Olorunfemi, 1983). However, surveys do not allow a reconstruction of historical changes in the landscape, whereas methods such as aerial photograph analysis, remote sensing and change detection may be used to analyse changes in land use and land cover (LULC) to inform land management decisions (Amini Parsa *et al.*, 2016; Moulds *et al.*, 2018). Although the strength of such analyses depends on the accuracy, cost, and resolution of the available imagery, such methods have proven useful when formulating guidelines for restoration, especially in developing countries where

data are often scant or non-existent (Ai *et al.*, 2020). Although useful for identifying the rate, nature, and extent of LULC changes, geographic information system technologies are not fully able to provide explanations regarding the underlying drivers and perceptions of these trends. Several studies have proposed assessing stakeholder perceptions as a complementary tool to better understand these dynamics (Munthali *et al.*, 2019; Kariuki *et al.*, 2021).

We employed an interdisciplinary, mixed-method approach using remote sensing, the collation of historical data, and stakeholder interviews to investigate the extent to which a degraded yet ecologically important river in the Western Cape of South Africa should be restored. We aimed (i) to investigate the historical and social-cultural contexts of the landscape which influence stakeholder perceptions of invasive alien species (Potgieter *et al.*, 2020); (ii) to understand the ecological and social drivers of invasions (Chaffin *et al.*, 2016); (iii) to evaluate the social values, and perceptions of stakeholders associated with invasive alien species and their management (Curtin and Parker, 2014); and (iv) to recommend sound planning strategies (Dufour and Piégay, 2009).

Theoretical Framework

Because a key goal of many restoration projects is to improve the delivery of ecosystem services, efforts should be directed to meet social-ecological goals instead of focusing solely on ecological outcomes (Dufour *et al.*, 2011; Abelson *et al.*, 2016; Gann *et al.*, 2019). Employing a social-ecological systems approach, which promotes a more integrated and holistic understanding of the interconnection between humans and nature, is therefore desirable for the restoration of degraded landscapes (Adams *et al.*, 2020). Cooperation and collaboration between all stakeholders and an understanding of the relationships between ecosystem functioning and ecosystem services is necessary to guide management.

The ecosystem services concept has increasingly been used as a tool in decision-making and management over the last two decades (Alexander *et al.*, 2016). However, conflicts can arise when restoration projects aim to target individual services rather than a full spectrum of ecosystem services (Bullock *et al.*, 2011). This is often the case for invasive species management, as many invasive species generate both benefits and costs to ecosystems and to society (Bullock *et al.*, 2011; Van Wilgen *et al.*, 2011). Analysing ecosystem bundles (sets of ecosystem services that appear together repeatedly across space or time) has been proposed as a tool for assessing common ecosystem service trade-offs and synergies in social-ecological systems (Karieva *et al.*, 2007). The concept of ecosystem services bundles thus enables management to objectively evaluate ecosystem services; this helps to resolve conflicts of interest, contributing to the effective management of multi-functional landscapes (Le Maitre *et al.*, 2011).

Ecological restoration has been defined as 'the process of assisting the recovery of damaged, degraded, or destroyed ecosystems to a reference condition' (SER, 2004). However, total recovery of degraded ecosystems is difficult to achieve at large spatial scales due to factors such as threshold-level changes in ecosystems, limited resources, poor management, diverse and incompatible stakeholder aspirations for change, and a lack of stakeholder interest (Novoa *et al.*, 2018; Adams *et al.*, 2020; Gaertner *et al.*, 2012). Rehabilitation is one of several activities along the restorative continuum and aims to reinstate a level of ecosystem functioning for ongoing provision of ecosystem services, where restoration to a reference ecosystem is not feasible in the short to medium term (Gann *et al.*, 2019). In the long-term, rehabilitation may be a first step towards full-scale restoration (Alexander *et al.*,

2016), however, for rivers in highly modified landscapes where total native ecosystem recovery is no longer possible, rehabilitation may be a more appropriate goal (Holmes *et al.*, 2020).

In social-ecological systems where interactions between social and ecological components operate at multiple temporal and spatial scales, complexity arises due to interactions between factors such as land-tenure patterns, societal preferences, and policy. Such complexity complicates decision making, often emphasizing the gap between science and practice (Reyers *et al.*, 2015). This gap can be addressed by restoration-based education, a process whereby stakeholders possessing technical knowledge (e.g. researchers and specialists) are trained to run educational programs for local people to help them acquire knowledge about degraded ecosystems and to facilitate the recovery of these systems (Garzón *et al.*, 2020; Pérez *et al.*, 2019). Additionally, bringing multiple sectors, disciplines, and stakeholders together to 'co-produce' knowledge has been recommended as a solution to understand and adaptively manage social-ecological systems (Steger *et al.*, 2020). In this context, knowledge co-production is regarded as an iterative, transdisciplinary process that integrates diverse knowledge systems and capacities from various stakeholders (both academic and non-academic) through a collaborative social learning process with the intention of generating innovative and legitimate knowledge to inform decision-making (Djenontin and Meadow, 2018; Angelstam *et al.*, 2017).

Methods

Study area – the Dwars River

The Dwars River valley (33°58'S; 18°58'E) is situated in the Western Cape, a drought-prone region of South Africa (**Figure 53**). It is a key water supply source for agricultural irrigation and the river and its banks are used by the surrounding communities for recreational activities (i.e. swimming, picnicking, and walking). The landscape comprises a mixture of privately owned farms and three peri-urban settlements characterized by complex land tenure patterns and governance. The combined population of the three settlements in the catchment is 10 700 people, and the population density is 4049/km^2 (Statistics South Africa, 2011). The Dwars River valley has a Mediterranean climate with wet winters and warm or hot dry summers. Riparian zones within Mediterranean climate regions are highly susceptible to biological invasions due to common disturbance-driven resource fluctuations such as flooding and drought events, as well as nutrient pulses that create new habitats for alien species colonization (Galatowitsch and Richardson, 2005; Stella *et al.*, 2013).

The natural vegetation along the Dwars River riparian zone has largely been replaced by agricultural land and invasive plant species, notably *Alnus glutinosa* (Black Alder), *Acacia melanoxylon* (Blackwood), *Populus alba* (White Poplar), *Acacia dealbata* (Silver Wattle), *A. saligna* (Port Jackson), and *A. mearnsii* (Black Wattle) (Belcher *et al.*, 2015) (see Supplementary Material S1 for species list). The lower section of the river has the largest known invasive population of *A. glutinosa* in the Western Cape (Keet *et al.*, 2020). The Biodiversity Spatial Plan Map indicates that the entire Dwars River valley has been designated an ecological support area, meaning that it plays a vital role in supporting the ecological functioning of Critical Biodiversity Areas (Pool-Stanvliet *et al.*, 2017).

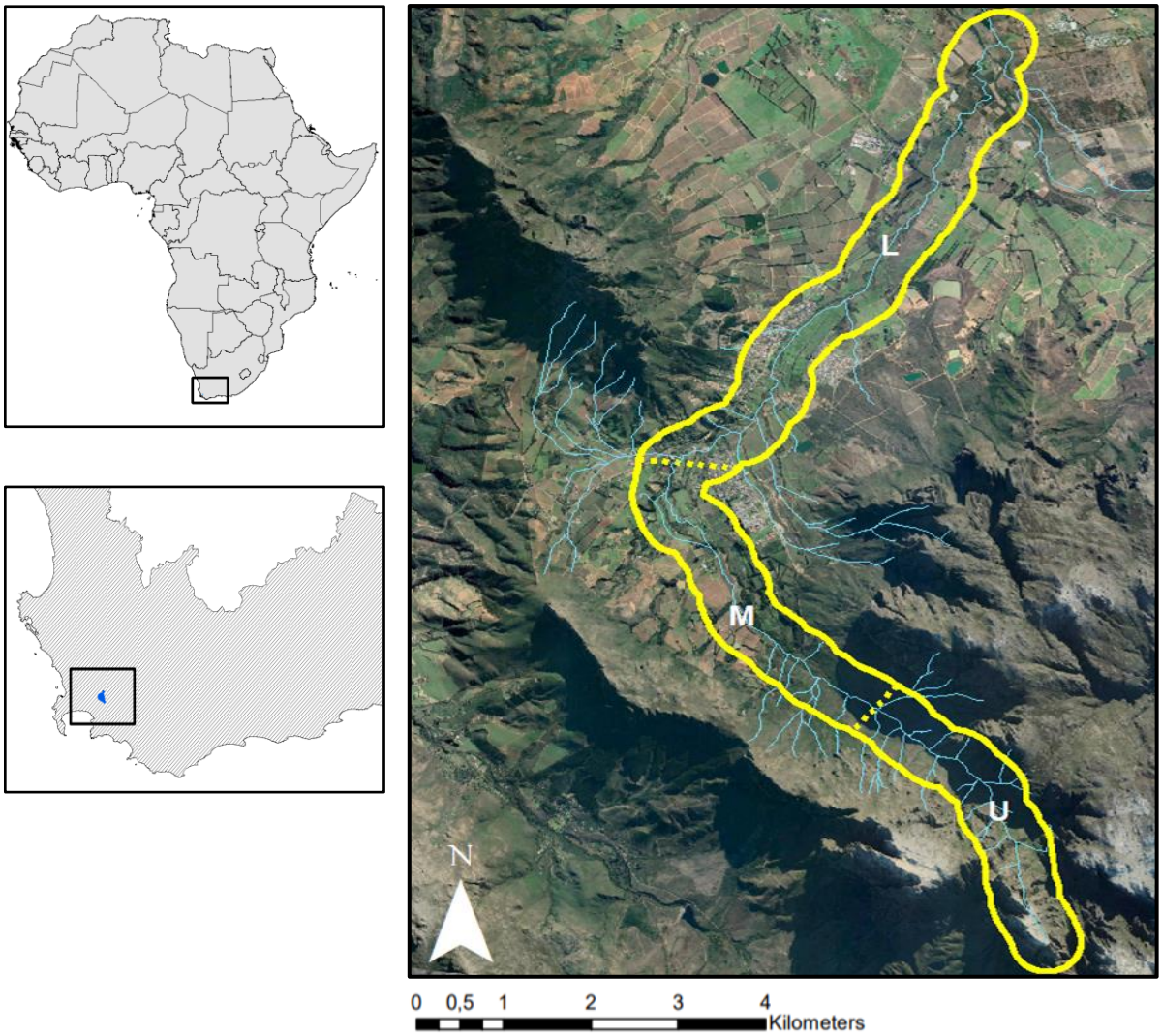


***Figure 53**. The location of the Dwars River study area within the Western Cape of South Africa is shown in the two left hand side panels. The enlarged aerial photograph shows the study area (solid yellow line), which is the riparian zone, defined as a 250 m buffer on either side of the river. The study area is divided into three sections, namely L = lower section, M = middle section and U = upper section (dotted yellow lines demarcate each section) defined according to the two main watershed basins (image retrieved from Google Earth).*

From August 2018 to the end of 2019, dense stands of invasive trees were cleared along the lower reaches of the Dwars River by a conservation trust with government funding. However, there are issues with the sustainability of this funding, impacting adequate follow-up maintenance, resulting in coppicing and re-invasion of species such as *A. glutinosa* and *A. saligna* (Keet *et al.*, 2020).

Historical context of the Dwars River valley

Historical sources such as diary entries, landscape paintings and maps can aid in reconstructing landscapes prior to impacts such as plant invasion (Gann *et al.*, 2019). In this study, a historical synopsis of the land was compiled using methodology similar to that applied by Van Rensburg *et al.* (2017). Firstly, information was obtained from personal communication with landowners. Although this information was mostly anecdotal, it advanced our understanding of how land use has changed over the last century. Secondly, historical records including old photographs, diary extracts, maps and land surveys were accessed from the Pniel Museum. Thirdly, a book titled 'Beautiful Banhoek'

(Hayden, 2015) provided a rich history of the Dwars River valley from the arrival of early settlers, slaves, and farmers to the present day.

Land use and land cover change analysis

Land use and land cover (LULC) surrounding the Dwars River over six decades was digitized using 1:30 000 aerial photographs from 1953 (the earliest available image), 1972, 1990 and 2016 (the most recent available image), using an approach described by Rebelo *et al.* (2015). Spatial resolution of the aerial photographs varied; 2016 had the highest resolution (0.5 by 0.5 m) and 1953 had the lowest (3.5 m by 3.5 m). Rebelo *et al.* (2017) highlight that in South Africa, aerial photographs are superior to any other form of remote sensing for smaller areas due to their high temporal resolution. Imagery was acquired from the Chief Directorate: National Geo-spatial Information, South Africa. Images for 1972 and 1990 were selected as they were the only aerial photograph series taken of the entire study area over the period 1953-2016 with a relatively equal time gap. Imagery was georeferenced in ArcMap (v.10.4.1) using the most recent and highest resolution orthorectified photograph from 2016 as the reference image.

Fourteen LULC classes were digitized; these included classes of invasive alien trees and weeds, agriculture, fallow land, bare soil, infrastructure and native vegetation (**Table 5**). Crops that are currently farmed in the region are mainly grapes and deciduous fruit (citrus, plum, pear, peach, apple), while several farms grow proteas, maize, lucerne and vegetables. Land use and land cover was digitized for each of the four sets of aerial photographs.

It is often difficult to accurately classify LULC from scanned maps and thus a small degree of error can emerge during visual interpretation, whereby each land use and land cover category is identified and digitized (Jain *et al.*, 2016). The accuracy of the output of the final LULC classes thus depends heavily on the interpreter. The most difficult class to discriminate was that of wetlands, particularly in mountainous areas. However, as this study focusses mainly on the extent of invasive alien plants rather than wetlands, such error was not considered to be of great significance. Historical and anecdotal information confirmed that alien tree species have dominated the riparian zone for the last century.

Digitization of the most recent photograph (2016; hereafter the 'reference image') was supplemented by several data sources. Cape Farm Mapper (v.2.3.2.9) and Google Earth helped confirm features such as wetlands, windbreaks, roads, water basins and crop types. Data accessed from Google Earth Pro included historical aerial photographs (using the time slider tool), Google Street View and public photos stored in the database; while Cape Farm Mapper provided a crop census from 2017/2018, based on aerial photography from 2016 (Western Cape Department of Agriculture, 2018), as well as a wetland dataset (Van Deventer *et al.*, 2018). The distribution of alien tree species in the reference image was verified by a GIS dataset provided by Holden and Rebelo (2019). Drone footage of the Dwars River valley helped guide the interpretation of various classes of the reference image (Holden *et al.*, 2021). Additional verification was done by ground-truthing of various sites along the river to identify the dominant invasive species. Historical imagery stored in Google Earth was also used as a supplementary source to cross-check imagery taken prior to the reference image.

Percentage cover assessments were conducted to establish the change in LULC classes over the four time intervals over the 63 years. This was established by summing area and perimeter data for the LULC classes for each year and comparing them between the four years. Relative change and absolute change in LULC classes were calculated. Invasion sources (hardwood blocks, windbreaks, urban areas) and possible dispersal routes (roads and rivers) were differentiated from invasion sinks (riparian and terrestrial infestations). To examine whether different parts of the riparian zone are undergoing changes in invasive alien tree cover at different rates, we divided the study area into three sections: (1) upper, (2) middle and (3) lower, according to the two main watershed basins within the study area (**Figure 53**).

***Table 5**. Land use and land cover classification scheme of the study area, defined by a 250 m buffer on either side of the Dwars River, Western Cape, South Africa.*

LULC class	Description
Agriculture	Crop fields, planted pastures, and natural grazing lands
Bare soil	Land with exposed soil, sand or rocks
Fallow	Grassy patches with no obvious signs of current agricultural use
Native vegetation (riparian)	Native plants occurring naturally within the riparian zone
Native vegetation (terrestrial)	Native shrubland and forest patches mainly inhabiting rocky scree slopes
Alien trees (hardwood)	Trees planted for wood
Alien trees (terrestrial)	Trees > 2 m that have invaded a terrestrial area
Alien trees (riparian)	Invasions of alien trees within the riparian zone
Alien trees (windbreak)	Alien trees planted in a single row around the edges of fields to shelter them from the wind and soil erosion
Alien weeds	Herbaceous plants < 2 m that have invaded an area
Roads	Major highways, minor roads, dirt roads and hiking paths
Urban	Buildings and other man-made structures (e.g. school fields, tennis courts, recreational facilities, parking lots)
Waterbodies	Streams, rivers, dams, reservoirs
Wetlands	Areas of land that are saturated with water throughout the year, as well as non-perennial seeps

The Mann-Kendall test (Kendall, 1948) was used to analyse data collected over time to determine monotonic trends. Using the trend package (Pohlert, 2020) in RStudio, we compared the spread of the five classes of alien vegetation within the three river sections (lower, middle, upper) between 1953 and 2016 to establish where the spread of invasion was most significant and to determine which class of alien vegetation experienced the greatest changes in area. The Mann-Kendall test is useful in describing which trends are most powerful (Jain *et al.*, 2016). The Mann-Kendall 'S' statistic indicates whether monotonic trends are increasing (positive S) or decreasing (negative S). The greater the value, the more powerful the trend whilst a value of 0 suggests that there is no trend.

Stakeholder interviews

To help understand public perceptions of invasive alien trees and ecological restoration, we conducted a set of semi-structured interviews (of approximately 30 minutes duration) between September and October 2020. Using purposive and snowball sampling (Creswell and Creswell, 2014), a total of 10 people who owned or managed properties bordering the Dwars River were selected (hereafter referred to as 'landowners'). Most interviews were conducted face-to-face (adhering to strict Covid-19 protocols), but some were done telephonically. For the relatively small sample size, a broad range of landowners were interviewed, from small homeowners to landowners of large commercial farms, the aim being to capture a diverse range of perceptions. To determine how much land within the study area was represented by the group of interviewees, we summed the area of each landowner's property occurring inside the study area, utilizing erf boundaries to delineate properties. From this, we calculated the overall percentage of land that was represented by the ten interviewees.

The questions asked in the interview are based on three broad topics that Gamborg *et al.* (2019) used in a similar process (see Supplementary S2 for interview questions). These topics include landowners' views on invasive alien species, their expectations of ecological restoration activities, as well as their willingness to be involved in future restoration efforts. The interview included several closed-ended questions in the form of Likert scales and Yes-No questions and a few open-ended questions. Each interview was recorded and transcribed, and data about the landowner and property were entered into a table (location, type and size of property, number of years spent on property) (Boyer *et al.*, 2019). Due to the nature of the semi-structured interview schedule, both quantitative and qualitative analysis could be applied. Close-ended questions were quantitatively analysed by summing responses from each category and expressing these results as percentages, whilst follow-up open-ended questions were organized into themes for each question and quotes were extracted to provide context. Themes were developed inductively for each question to understand patterns in the data without any pre-existing frame of reference, i.e. using phrases or terms used by the participants themselves (Richards and Hemphill, 2018). This enabled us to offer credible interpretations and comparisons of the empirical material.

To deepen the understanding of our results, we conducted an unstructured interview with the project manager of a conservation trust active in the study area. The aim of the interview was to develop a better understanding of the restoration strategy, as well as challenges and barriers faced by the implementer.

Results

Historical context of the Dwars River valley

It was after 1687 when the Dutch Vryburger settlers were allocated land in the Dwars River valley that human activities began having a clear effect on the landscape (De Wet, 1987). The Vryburgers were soon joined by the French Huguenots who had been exiled to the Cape. Together, the two groups divided the land into small parcels to keep cattle, sheep, and to plant grape vines (Coertzen *et al.*, 1988). The first landowner of the Dwars River valley is said to have been Jean le Long, a Huguenot who was allotted the farm 'Bosendaal' (now Boschendal) in 1685.

An account of the farm was given in 1705 by minister Francois Valentyn:

> *Here is one of the most noble estates that can be imagined… The house lies in a pretty and ornamentally laid out wood of lovely oaks* (Hayden, 2015:4).

This quote confirms that oak trees (*Quercus robur*) were well-established in the region in the early 18th century. This evidence is supported by Potgieter *et al.* (2020) who reported that oak trees were brought to the region by early European settlers as feature trees and for their use as timber products.

Although we could not find any evidence as to when and why invasive Australian *Acacia* species were brought to the Dwars River valley, it is widely known that some species were brought to the Cape in the 19th century for tannin production and sand drift control, and several decades later, other species were brought for timber production (Le Maitre *et al.*, 2011). According to Urgenson *et al.* (2013), landowners were incentivized by the State through 'tree growing competitions' to grow alien trees on their properties to render South Africa independent of international wood and timber markets. It is thus highly probable that *Acacia* species were brought to the Dwars River valley for similar reasons and spread to the riparian zone in subsequent years.

By 1960, several alien species were recognized as problematic, and widespread campaigns to remove invasive alien plants were initiated in the 1980s. The Conservation of Agricultural Resource Act (Act 43 of 1983) was proclaimed to regulate designated invasive alien plants on public and private land. Later, a more comprehensive piece of legislation was enacted, the National Environmental Management Biodiversity Act (Act 10 of 2004) which is in effect today.

Land use and land cover change analysis

There have been a few noticeable patterns in the overall extent of the LULC classes over the past 70-years (**Figure 54**). Within the riparian zone of the Dwars River, native terrestrial vegetation and agricultural land covers the largest total area. Herbaceous alien weeds (<2 m tall) remained relatively constant across the first three time periods but had increased markedly by 2016. A similar but opposite trend can be observed for hardwood blocks, the extent of which remained relatively unchanged until 1990 when there was a rapid decline.

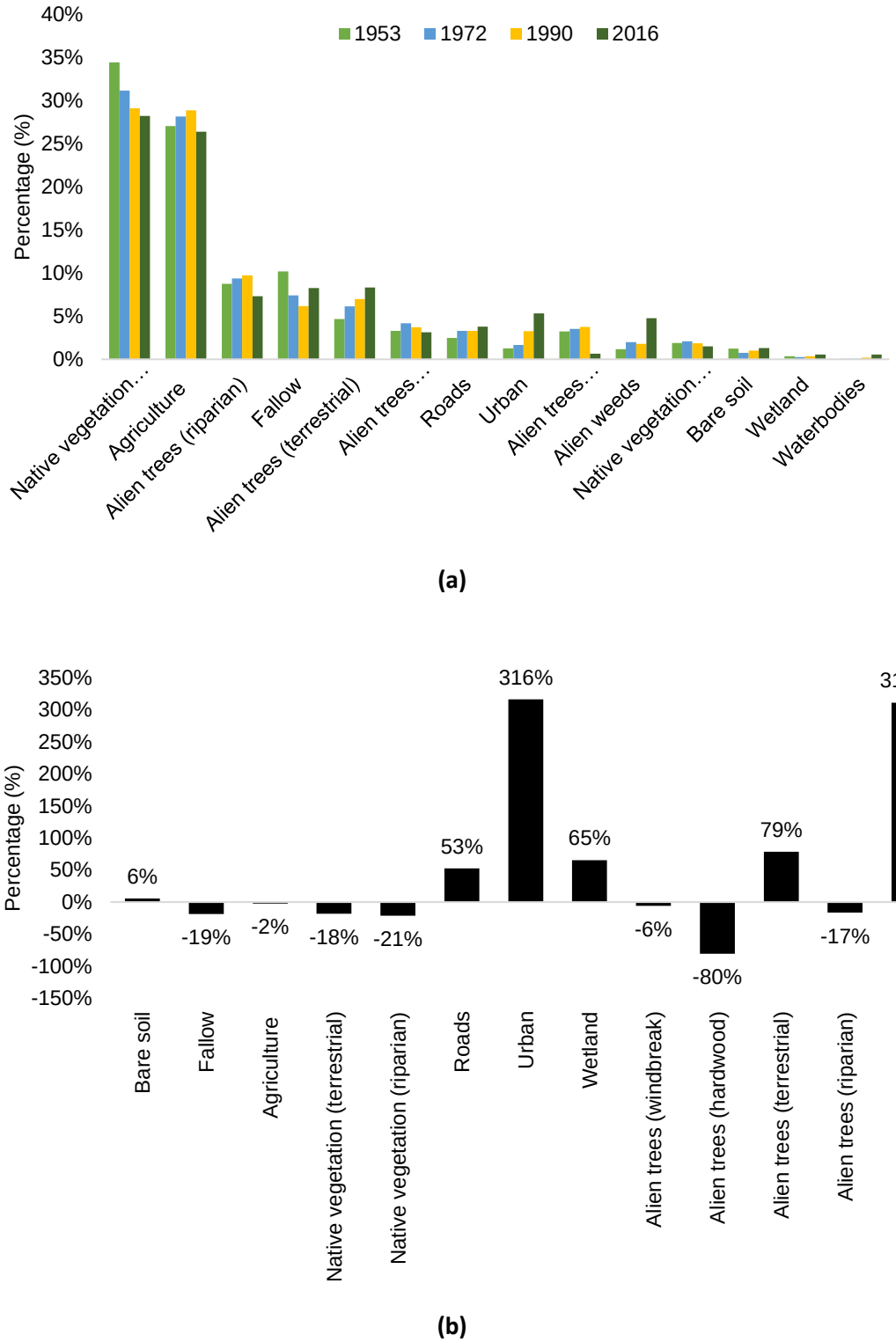


***Figure 54**. (a) Percentage of the total study area that each land use and land cover class occupies for each of the four time intervals considered: 1953, 1972, 1990 and 2016 within the riparian zone. (b) Relative change in the area represented by each land use and land cover class between the earliest year that was mapped (1953) and the most recent year (2016) represented by (2016-1953/1953). To prevent distortion, waterbodies (value of 1074%) have been removed*

In terms of relative change, the most significant increase in average area within the riparian zone between 1953 and 2016 was that of waterbodies (1074%), mainly small farm dams. Several other

significant increases were that of urban areas (316%), as well as alien weeds (311%), which both increased more than three times their initial extent in 1953. Alien terrestrial trees (79%), wetlands (65%), and roads (53%) also showed substantial expansion in average area between 1953 and 2016. Relative change calculations also indicated several decreases in average area, with the greatest being that of alien hardwood blocks (-80%).

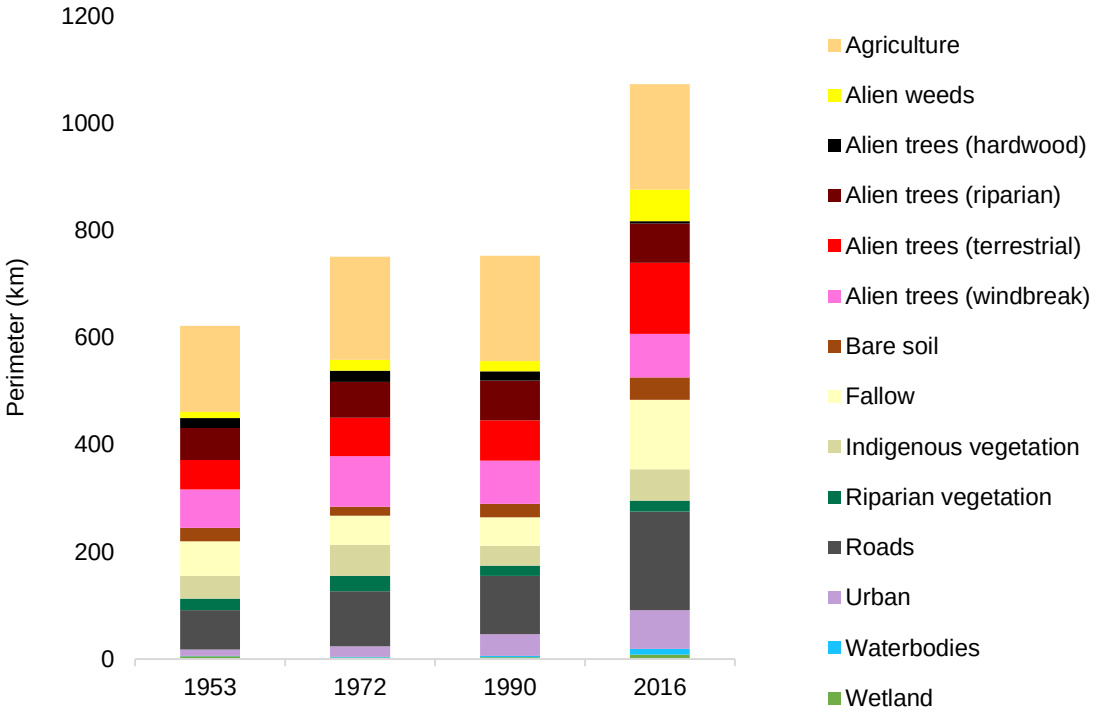


Figure 55. *Change in total perimeter (km) of each land use and land cover class for the four time intervals mapped within the study area: 1953, 1972, 1990 and 2016.*

The total perimeter of all LULC classes increased most markedly within the riparian zone between 1990 and 2016, increasing from 752.37 km to 1072.42 km (**Figure 55**). Perimeter increased monotonically between the years for four LULC classes: alien terrestrial trees, roads, urban areas, and waterbodies.

Comparing changes in land use and land cover between the lower, middle and upper sections of the riparian zone

In the upper-middle section of the riparian zone there has been substantial infestation by invasive alien trees (**Figure 56**). As there were few or no alien tree stands present in this area in 1953, this invasion must have occurred between 1953 and 1972. Alien weeds ($S = 6$, $p = 0.089$) and alien terrestrial trees ($S = 6$, $p = 0.089$) have increased significantly in the middle section of the riparian zone of the Dwars River (see Supplementary Material S4).

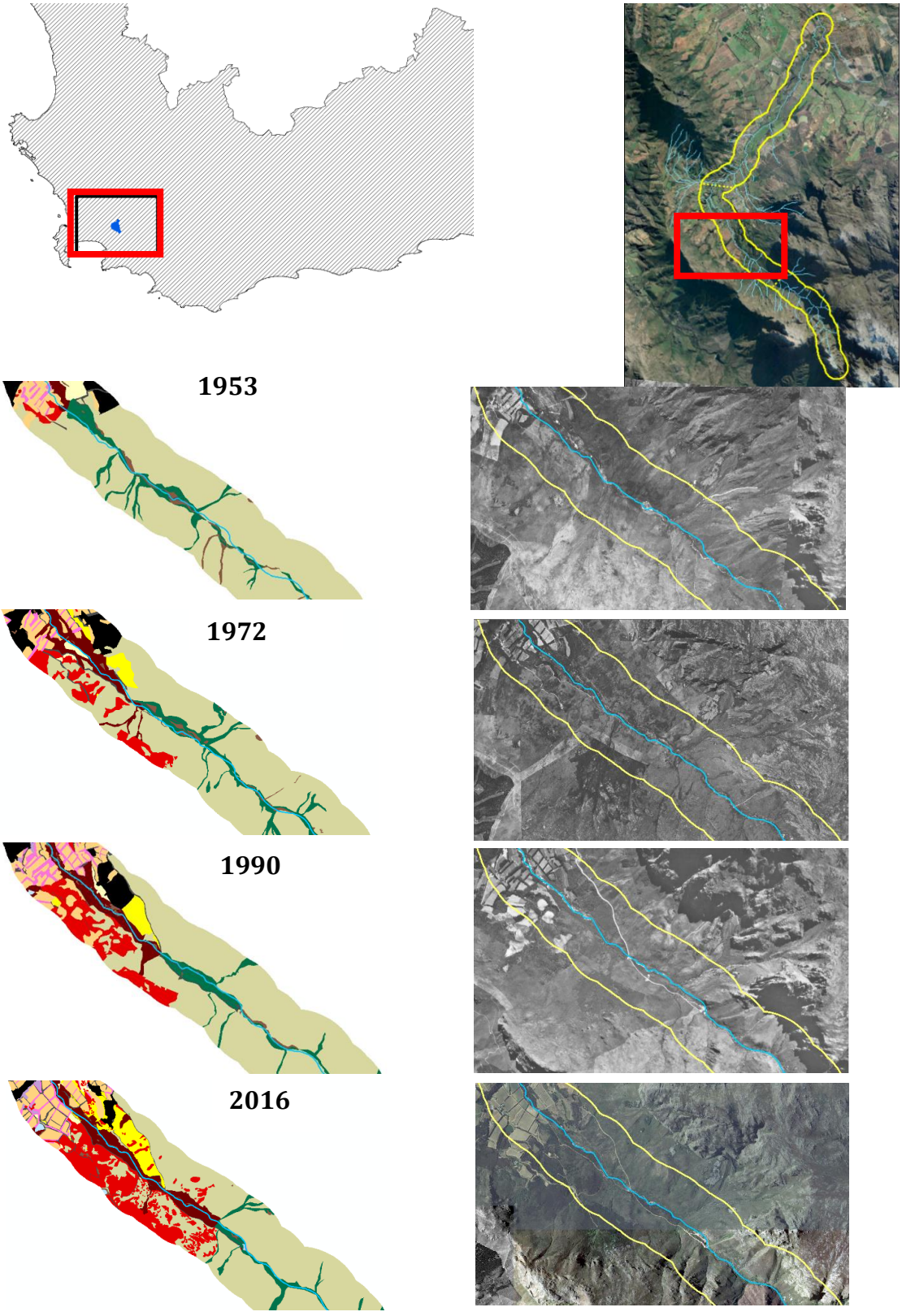


***Figure 56**. Snapshots of the upper-middle reach of the Dwars River, in the Western Cape of South Africa, highlighting the rapid spread of invasive plants: ■ alien trees (terrestrial), ■ alien trees (riparian) and ■ alien weeds from 1953 to 2016. Other important land-use and land cover changes include ■ agriculture, ■ waterbodies, ■ native vegetation (riparian), ■ alien trees (windbreak) and ■ alien trees (hardwood) (see Supplementary Material S3 for entire maps).*

Stakeholder interviews

When asked why the conservation trust decided to target dense invasions in the lower reaches of the river instead of sparse infestations in the upper reaches, the latter more likely to recover ecologically through spontaneous succession (Holmes *et al.*, 2020), several barriers were listed including: financial constraints, an inappropriate funding model, a lack of engagement among stakeholders, institutional challenges, and a lack of techno-scientific knowledge (**Table 6**). Additionally, this site was prioritized because the project manager wanted to tackle what they perceived to be the 'biggest problem first' which was thought to be the dense invasions of *A. glutinosa* occurring within this site (i.e. to reduce the source of propagules for the rest of the Berg River downstream). Additionally, the team wanted to work in an area with big visual impact for the community, for people to see the difference.

***Table 6**. Barriers preventing successful implementation of previous alien clearing efforts along the riparian zone of the riparian zone of the Dwars River, Western Cape.*

Barriers to successful implementation of alien clearing strategies	
Inadequate financial resources	Government funding allocated to alien clearing work was insufficient, posing barriers to working in an ecologically strategic way (e.g. targeting sites that were within walking distance of workers' homes to reduce transport costs).
Inappropriate funding model	The contract stipulated by the funding model was very short, making it impossible to create connections with a diverse group of stakeholders, and to interact with the funder for guidance (e.g. appropriate guidance on herbicide use). Additionally, only 22% of the budget could be allocated to stakeholder engagement, thus the amount of effort and time that could be invested in outreach and community engagement was severely constrained.
Lack of engagement with private landowners	Many private landowners were unwilling to support alien clearing activities as they are disconnected from the river, either because they live elsewhere or because they do not physically interact with it, or there is high ownership turnover. Additionally, some landowners were unwilling to have external workers on their properties due to cited safety reasons, or because invasive alien trees hide illegal activities like water abstraction. A platform to engage landowners did not exist.
Institutional challenges	Communication with government was difficult due to a rapid turnover of staff working for the Municipality (time and effort was needed to build relationships within government, and when there was turnover of staff, the work had to be started again due to a lack of an adequate handover, or due to lack of interest from the new staff).
Lack of techno-scientific knowledge	While the knowledge exists to work in ecologically strategic ways, these are not necessarily known or understood, especially by smaller contractors.

The combined area of land owned or managed by the 10 landowners was calculated to be 4339.18 ha (43.39 km^2). Of this, the area of land that falls within our study area is 965.64 ha (9.67 km^2) which is equal to 46% of the total study area. Properties of landowners were all located adjacent to the Dwars River, with an almost equal representation from both the lower and middle sections of the river.

***Table 7**. General information about each interviewee's property and the number of years spent on the property.*

	Area of property (ha) within study area	Percentage of total study extent (%)	Type of property	Section of river that property borders	Years on property
1	7	0.34	Household with a garden	Middle	11
2	217.88	10.49	Large-scale farm (one type of crop)	Middle and upper	24
3	0.07	0	Household with a garden	Lower	29
4	0.06	0	Household with a garden	Lower	8
5	0.05	0	Household with a garden	Lower	9
6	25	1.20	Small-scale farm (many types of crops)	Lower	19
7	48.68	2.34	Large-scale farm (one type of crop)	Middle	13
8	404.96	19.50	Large-scale farm (many types of crops)	Lower	4
9	73.03	3.52	Large game farm	Lower and middle	10
10	188.92	9.10	Large-scale farm (many types of crops)	Middle and upper	20

All participants expressed concern regarding the health of the river. When prompted for further information, three landowners living adjacent to the lower section of the river mentioned the poorly functioning sewerage system built on the riverbanks:

> *There is raw sewage that flows into the river through a pipe and it deteriorates the water quality. Most days you can smell the sewerage. It is a health hazard to our kids who swim and play in the water.*

In terms of water use, three of the largest farms have rights to abstract water from the river which they use for irrigation, and thus have a financial interest in keeping it clear of invasion.

All ten participants had prior knowledge of invasive alien trees species and were able to provide examples. When asked if they thought all alien trees are detrimental to nature, participants had varying opinions. Overall, most people felt that that not all alien trees are detrimental to nature. One landowner mentioned that he had planted Water Oak (*Quercus nigra*) trees along the riverbanks seven years ago, despite knowing they are alien species.

Although I know they are not indigenous, I do not want my Water Oaks removed. I think they are beautiful, and they stabilize the banks of the river. It would break my heart to see them go after seven years.

A similar opinion was held by two other landowners, who mentioned that they were upset when *A. melanoxylon* trees had been cut down on their properties by external contractors. As this tree species is listed as a category 1b invasive species under the National Environmental Management Biodiversity (Act 10 of 2004), by law, landowners need to allow an authorized official to enter their land to control the prohibited species. On the other hand, two other landowners had a slightly different argument. The first mentioned that after he had cleared *Eucalyptus* trees on the mountain within his property, he witnessed how the mountain spring continued to flow throughout the drought of 2018. The second felt that although alien trees may have short term benefits – they should ultimately be removed as they have excessive water requirements.

When asked if they are willing to contribute effort to restore the Dwars River, half of the participants acknowledged they could be doing a lot more, whereas two believe they are already doing a lot (**Figure 57**). Those who believed they could do more involved suggested helping with physical labour and planting more native trees along the river.

When asked whether ecological restoration should be made a priority along the Dwars River, most landowners agreed that it should.

Table 8 highlights the range of perspectives amongst the ten interviewees

***Table 8**. Landowners' perceptions of ecological restoration of the Dwars River, Western Cape.*

Strongly in favour of ecological restoration	We need to do it for our kids so that we don't lose our rich biodiversity and heritage.
	I think that the more rivers that are cleared, the more everything is put back to the way it should be, and the better balance we will have with nature.
	Because the ecology sustains us and if we cheat the ecology, we put ourselves in danger.
	I think if it's good for water saving, then alien trees need to be removed. Nature should be there for us – it should not be to the detriment to us as a community.
In favour of ecological restoration on certain conditions	Yes – but it needs to be sustainable. Alien clearing must be followed up regularly otherwise they are going to keep taking over and reverting us back to square one. We need a proper plan and landowners need to work together, otherwise it is just going to be a waste of time and money.
	That is like asking me 'how long is a piece of string?'. To what point do you take it? Do you take 100% according to the book or only within what your financial capabilities makes it possible. I believe in it. I believe in the concept and that overall, it's good but where do you draw the line on how far one has to go to get to a 100% result. So, in principle, yes, but its practical implementation I'm not sure.
	The small farmers that don't have any interest in the river, we need more attention on them. We spend a lot of time, we clear, and on the other side of the river it's overgrown and dumped with rubbish. There needs to be more education.
	I think it is important to restore an ecosystem as much as possible to its original native state, and to incorporate new vegetation. But there needs to be follow up.
	Yes, but to restore to what stage? Before oak trees, or after oak trees? That's the big bone of contention.
Not in favour of ecological restoration	No. For me, it's just an environment which I can see and enjoy.

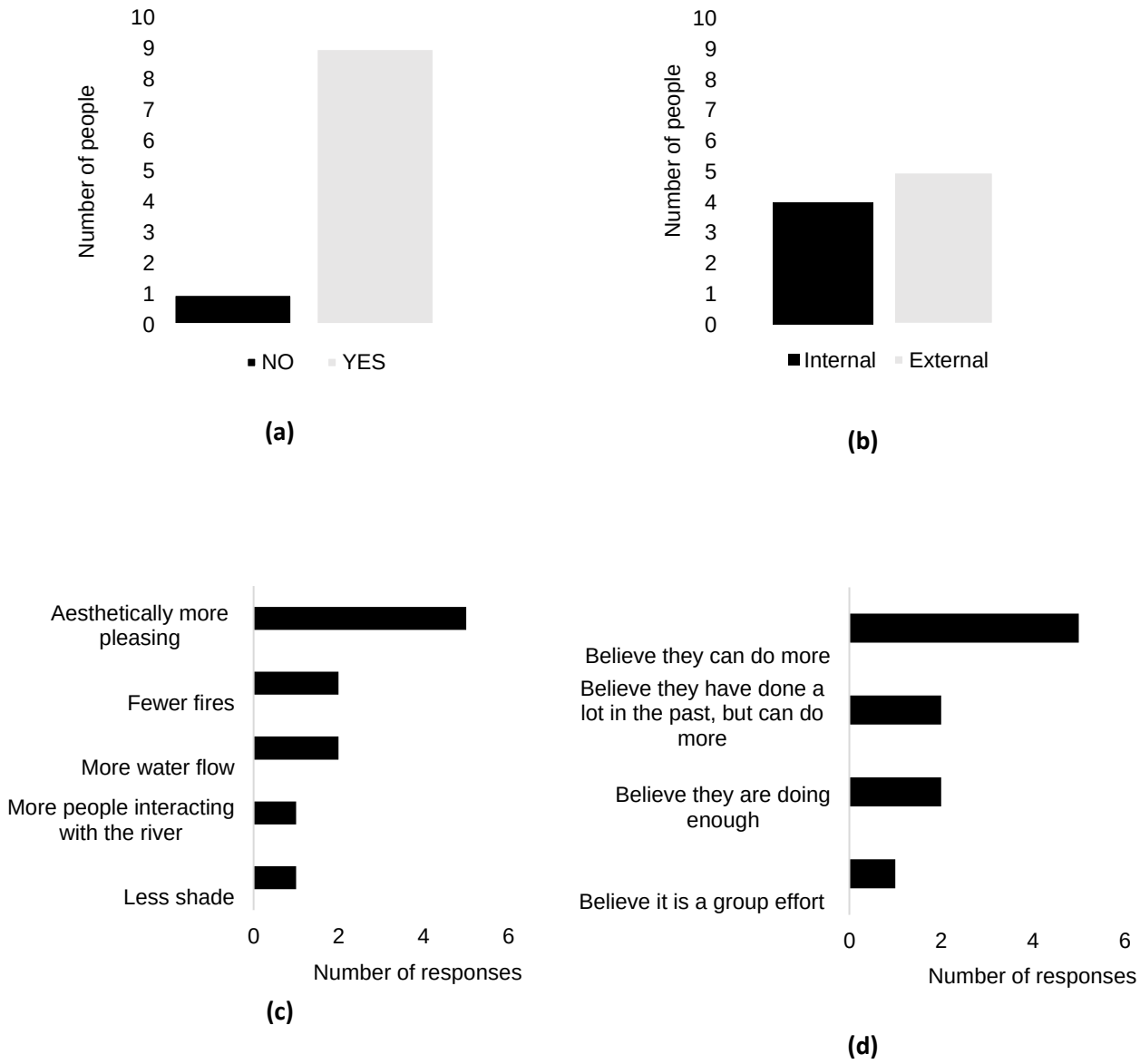


***Figure 57**. (a) An indication of whether or not alien clearing activities have taken place on landowners' properties in the last year. (b) Whether alien clearing activities were initiated internally by the landowner or externally by contractors or by government initiatives. (c) Reported benefits and costs that have resulted following alien clearing activities along the Dwars River. (d) Willingness of interviewees to get involved in future restoration efforts along the Dwars River, Western Cape.*

There was a wide discrepancy in response as to who should be responsible for conducting and funding alien clearing activities along the Dwars River (**Figure 58**). Only one person thought it should be an equal partnership between the land user and the government while the rest of the opinions were distributed relatively evenly between the other options.

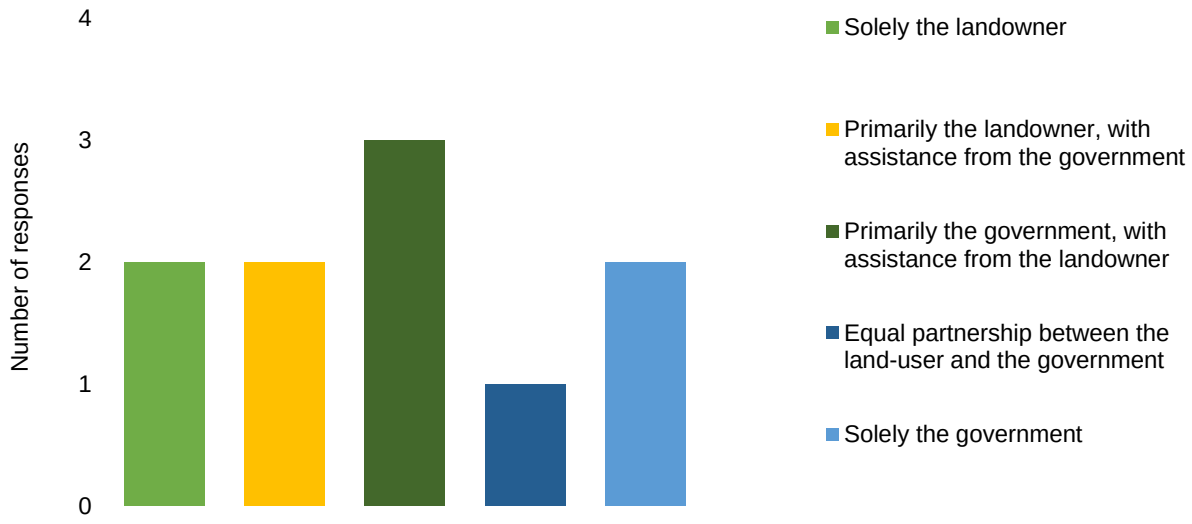


***Figure 58**. Participants responses when asked who should be responsible for alien clearing activities along the Dwars River, Western Cape.*

Several small-scale farmers shared the sentiment that they cannot afford to conduct regular alien clearing on their properties as it is expensive and time consuming, whilst one of the large-scale farm owners raised the point:

> *Even if I spend lots of money clearing my section, the effort is futile because if the landowner living 5 kilometres upstream from me doesn't clear his section, his seeds will eventually end up on my property.*

Discussion

We first discuss the findings in two sections: (1) ecological reflections of alien clearing based on land-use/land-cover change analysis, and (2) social reflections on perceptions of, and challenges around, alien clearing. Finally, we bring these reflections together to make recommendations from a holistic socio-ecological systems perspective.

Land-use/land-cover change as drivers of alien invasion of a riparian zone

As land use change has occurred in the Dwars River valley since the arrival of the European settlers over 300 years ago, there has been a long history of alien plant introductions into the area (Hayden, 2015). In the last 60 years, agriculture has been the dominant land-use activity of the riparian zone, remaining relatively unchanged in area. In contrast, urban areas have increased exponentially over the last six decades, almost tripling in size within the study area. This trend is characteristic of peri-urban settlements, known to expand rapidly on the urban fringe (Zivanovic-Miljkovic *et al.*, 2012). Possibly as a result of policy changes and agricultural intensification combined with the growing need

to improve water security under climate change, 12 new artificial farm dams have been constructed on private land between 1953 and 2016. Intensive cultivation is recognized as a driver of invasion in that large numbers of alien propagules are intentionally introduced to landscapes through horticultural trade and unintentionally via transportation. In terms of changing policy, abstracting water from South African rivers for private use was made illegal by the National Water Act (Act 36 of 1998). Despite this, our interviews revealed that some farmers still illegally abstract water from the Dwars River as there is little to no enforcement of regulations. Our findings also suggest that the natural habitat of the Dwars River valley has become more fragmented over time due to the increase in road networks, the increase in urban land, and the subdivision of farmland. Fragmented landscapes tend to be more disturbed and as a result are often heavily impacted by alien weeds which thrive in degraded sites (Nsikani *et al.*, 2020). Increased fragmentation of land is thus also a driver of alien weed invasion. We consider the abovementioned land use activities to be drivers of invasion as they alter hydrological flows and cause disturbance which facilitates the spread of invasive species (Richardson *et al.*, 2007).

The noticeable decline in alien hardwood blocks (most likely harvested for wood products) between 1990 and 2016 within the riparian zone has resulted in a significant increase in alien weeds in areas where these hardwood trees were cleared. This concurs with a study by Galloway *et al.* (2017) who documented evidence of secondary invasion, whereby short-lived alien plants rapidly invade land which was previously used for old pine plantations. In South Africa, few management interventions are currently targeting secondary invasions (Nsikani *et al.*, 2020). The extent of riparian vegetation dominated by alien trees remained relatively stable over the years, with a slight decline in the last 20 years. The recent decline in percentage cover of alien-dominated riparian vegetation is due to alien clearing projects such as that initiated by the conservation trust along the lower reaches of the river. Although there were some benefits acknowledged by the community (i.e. more aesthetic appeal after clearing), from an ecological point of view, these efforts have been inefficient due to several barriers preventing management from implementing the preferred ecological strategy; this points to the difficulties of working in complex socio-ecological systems (Liu and Cook, 2016). Holmes *et al.* (2020) recommend that the most cost-effective way of conducting alien clearing is to target sites which have not yet crossed biological thresholds. This should be done in 'top-down' fashion (i.e. starting at the source of invasion and working downstream) as alien propagules are often dislodged during clearing and transported further down the river (Le Maitre *et al.*, 2019). Once abiotic or biotic thresholds have been breached, native seed banks no longer persist, necessitating the implementation of expensive active interventions (Gann *et al.*, 2019). Thus, alien-plant clearing activities should be prioritized in sites with recent and/or low-density invasions to optimize spontaneous succession, such as sites in the upper-middle section of the Dwars catchment.

Complexities arising from social-ecological systems

Despite decades of sound ecological inputs and recommendations, and efforts to address the knowing-doing gap (Reyers *et al.*, 2015), implementers are not following ecological restoration protocols. What are the major barriers to successful implementation of rehabilitation interventions? We explore these both from the perspective of implementers and landowners.

Barriers to successful implementation of restoration and rehabilitation projects are context-specific, however in certain contexts (i.e. less developed countries), barriers tend to overlap (e.g. Castán Broto *et al.*, 2013). In our case study, several major barriers that are commonly experienced in developing country contexts were faced by the implementers (Shih *et al.*, 2019). First, budget and time constraints forced managers to cut corners and to neglect proper planning and stakeholder engagement

(Alexander *et al.*, 2016). Second, managing and monitoring rehabilitation efforts along the Dwars River has proven difficult in recent years due to a lack of competence in governance as well as siloed communication, leading to confusion over who is responsible for the management of invasive alien plants in the catchment. Adaptive collaborative governance, defined as 'the engagement of participants across boundaries of public agencies, levels of government and/or the public, private and civic spheres' (Emerson and Gerlak, 2014) is an approach that generates open and reliable communication and coordination systems between knowledge-producers and decision-makers to advance shared goals (Reyers *et al.*, 2015). Third, there is apparent lack of stakeholder interest and knowledge of invasive species and their management. Limited techno-scientific knowledge is a challenge faced mainly by developing country contexts where historical legacies of uneven development (e.g. colonialization and apartheid) yield different priorities and/or capacities to create or access knowledge (Shih *et al.*, 2019; Gaertner *et al.*, 2012). Angelstam *et al.* (2016) suggest that information, education, and communication are components of advocacy that persuade and mobilize people into action. If the science that underpins biological invasions and ecological rehabilitation is not well understood and supported by stakeholders, there is little chance that efforts to improve ecological functioning will succeed (Adams *et al.*, 2020).

The Dwars River valley comprises numerous land-parcels owned by a variety of landowners with diverse and sometimes conflicting perceptions and values of invasive alien species and on how they should be managed (Woodford *et al.*, 2016; Briske *et al.*, 2016; Dufour *et al.*, 2011; Potgieter *et al.*, 2020). Several landowners were opposed to the removal of certain alien tree species from their properties, or even actively planted them, whereas others understood the implications of invasions and supported the need for management. Some alien tree species, notably *A. melanoxylon* (Australian Blackwood) were considered 'beautiful' trees that should be kept because they 'stabilize banks and prevent erosion'. This perception is not only incorrect from an ecological perspective, but it too conflicts with policy. Legislation prohibits planting of these species in South Africa. In addition, Van Wilgen *et al.* (2020) showed how closed stands of alien trees reduce ground-layer vegetation thereby destabilizing soil which led to erosion of the riverbanks. Consequently, this increases the chance of flooding which puts human safety and property at risk. Thus, using the ecosystem-services concept (Bullock *et al.*, 2011), the ecosystem disservices (soil erosion, biodiversity impacts, water regulation) ultimately outweigh the benefits (aesthetic services) to society. There is therefore a need to address such misconceptions and trade-offs to prevent conflicts in future; this can be achieved through participatory workshops which has been shown to act as a communication platform for stakeholders to interact (Liu and Cook, 2015). Understanding the interests and expectations of landowners and actively involving them in all stages of restoration via knowledge co-production is crucial to ensure mutually beneficial relationship between society and nature (Adams *et al.*, 2020; Curtin and Parker, 2014). However, if landowners are unwilling to comply with the law, necessary action should be taken.

Although some of the wealthier landowners personally fund alien plant clearing on their properties, some landowners cannot afford the substantial investment of resources that are required to clear dense stands of invasive alien trees and to maintain regular follow-up control. This is a sentiment shared by landowners in most developing countries. As government is unable to provide the resources needed to implement long-term rehabilitation and restoration projects, there is an urgent need to involve landowners in collective support of conservation efforts along degraded rivers in water-scarce areas (Urgenson *et al.*, 2013; Meek *et al.*, 2013). An effective way to coordinate and manage common water objectives while providing joint benefits is to connect a body of stakeholders that are representative of the diverse demographic within the catchment area. If all concerned parties come together to address the issues, sustainable and long-term water security can be achieved through

collective efforts and shared responsibility. This collaborative action, known as water stewardship, has been implemented globally, with successful projects established in many countries globally (IwaSP, 2019).

Recommendations

- Funding models should be revised to allow inclusion of robust planning and adequate stakeholder engagement;
- Education of stakeholders and implementers through a collaborative social learning process should include consideration of a broader suite of ESs important to the community (i.e. wildlife habitat, wood resources) (through participatory workshops);
- Co-design more flexible financial models (such as combining stakeholder and government funds) to allow for correct management strategies (guided by science) to be implemented;
- Effective communication is needed to provide landowners with clear expectations regarding the level of invasive alien plant management and monitoring required over the long term;
- A stewardship programme should be initiated by implementers to unite a collective body of landowners in sharing the responsibility of rehabilitation the river.

Conclusion

The degradation of the Dwars River has been caused by a long history of land use and land cover change within the landscape, which has driven alien tree invasions in the riparian zone. Specific drivers include the clearing of old hardwood blocks in recent years, increased construction of artificial dams (impounding the river, changing hydrological regimes), water abstraction for irrigation and the increasing fragmentation of land due to increased road networks and the subdivision of farms. Inappropriate methods of alien plant clearing applied in the past have, in some cases, exacerbated invasions. Given this complex history and the limited resources available to support conservation actions, restoring the entire river to its historical state is perhaps unrealistic given the changed hydrological regime, physical changes to the river system, and the complex social-ecological system that now prevails (Meek *et al.*, 2013). This study has only considered alien tree clearing as one rehabilitation intervention and has not considered other measures such as geomorphological or hydrological rehabilitation (e.g. earthworks, and reinstating the ecological reserve). We have proposed several recommendations to rehabilitate the riparian zone, taking stakeholder perceptions and values into consideration. Interviewing stakeholders gave considerable insights on why previous efforts to control invasion along the Dwars River have failed (e.g. a lack of communication between stakeholders, limited funding). Landowners also contributed significant ground-level knowledge about the system including recent fire and flood events, relationships between stakeholders, and other threats to the river (e.g. illegal abstraction of the river water).

Our study contributes to the literature on restoring degraded ecosystems within complex social-ecological systems. By nature, these systems are inherently complex, presenting a diverse array of challenges to implementers. These challenges are compounded in developing countries which face problems such as poor governance, limited resources, and a lack of education. In circumstances where resources are limited, context-specific planning strategies should be devised prior to commencing ecological restoration. Even when the goal is not to restore to a past ecosystem state, a holistic view is needed to understand the context of a landscape to inform appropriate goals along the restoration continuum in the face of new barriers and opportunities in future. Effective communication amongst

stakeholders, education of the local population and adaptive collaborative governance will contribute to the success of future rehabilitation projects in South Africa and other developing countries.

Supplementary Material can be found in Appendix 5.

This work has been published as follows:

Du Plessis, N. S., Rebelo, A. J., Richardson, D. M., & Esler, K. J. (2021). Guiding restoration of riparian ecosystems degraded by plant invasions: Insights from a complex social-ecological system in the Global South. *Ambio*, 1-17.

3.1.3. Global Narrative: NATWiP International Team Workshop Results

Introduction

This WRC Project is part of a larger JPI research project with peri-urban nature-based solution case studies from several other countries and many project partners (see **section 1.3**). At the JPI mid-term meeting 2020, the South African team held a workshop with nine team members (participants) on 25 September 2020 with two aims: (1) to build a better understanding of all the case studies, and (2) to improve our understanding of the main challenges/barriers facing the nature-based solution implementation globally.

Methods

We asked participants to describe their case study(s). We assigned three mins per case study and asked participants to address the following four questions:

1 What is the main challenge(s) the nature-based solution is addressing?
2 Is your nation developed/developing?
3 What is the nature-based solution?
4 Describe/list the main challenges/barriers facing the nature-based solution implementation (considering ecological, socioeconomic, technological, political, legal, planning, governance, and institutional dimensions).

We then developed a survey, based on the results of the main challenges or barriers facing nature-based solution implementation for all JPI team members. This survey was completed in October and November 2020, and in November the results were analysed.

Results & Discussion

We received responses from researchers from six nations and nine case studies (**Figure 59**).

***Figure 59**. The spread of responses between countries from researchers that participated (n=9).*

We mapped the case studies in terms of their main challenge(s) being addressed, their economic status and project stage (**Figure 60**).

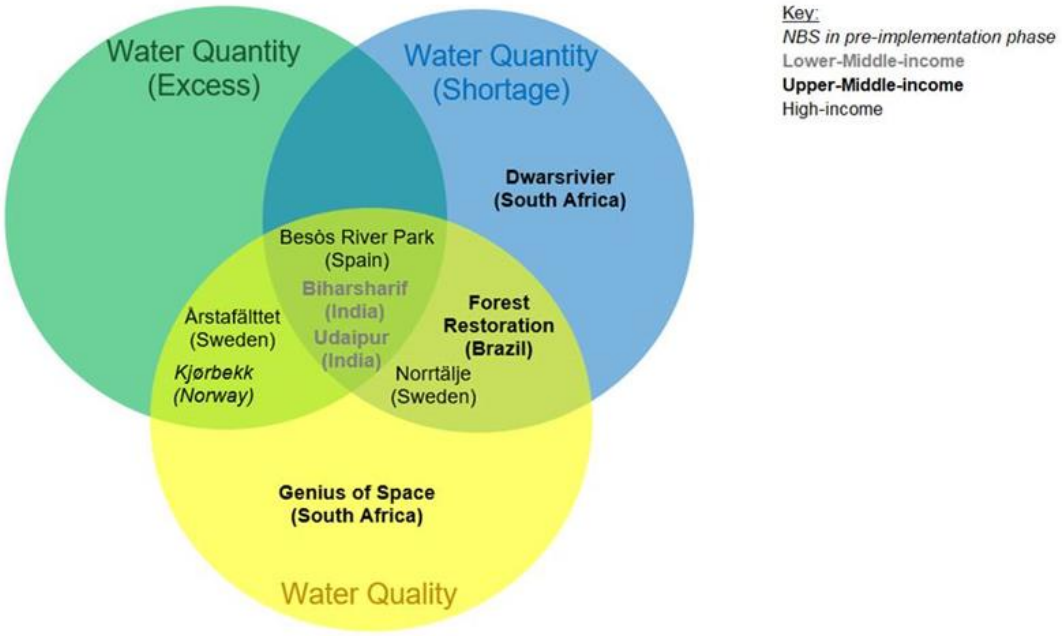


***Figure 60**. The results of the case study mapping exercise and how the case studies relate in terms of main challenge being addressed (water quantity or quality), their economic status and project stage.*

Suboptimal planning processes and sustainable funding emerged as the two greatest challenges in nature-based solution implementation, with lack of strategy, legal/policy context, rapid urbanisation and silo mentality also being highlighted as important (**Figure 61**). These findings are useful to inform future nature-based solution projects, as implementers will be able to anticipate possible risks and barriers and to find strategic solutions in the planning phase.

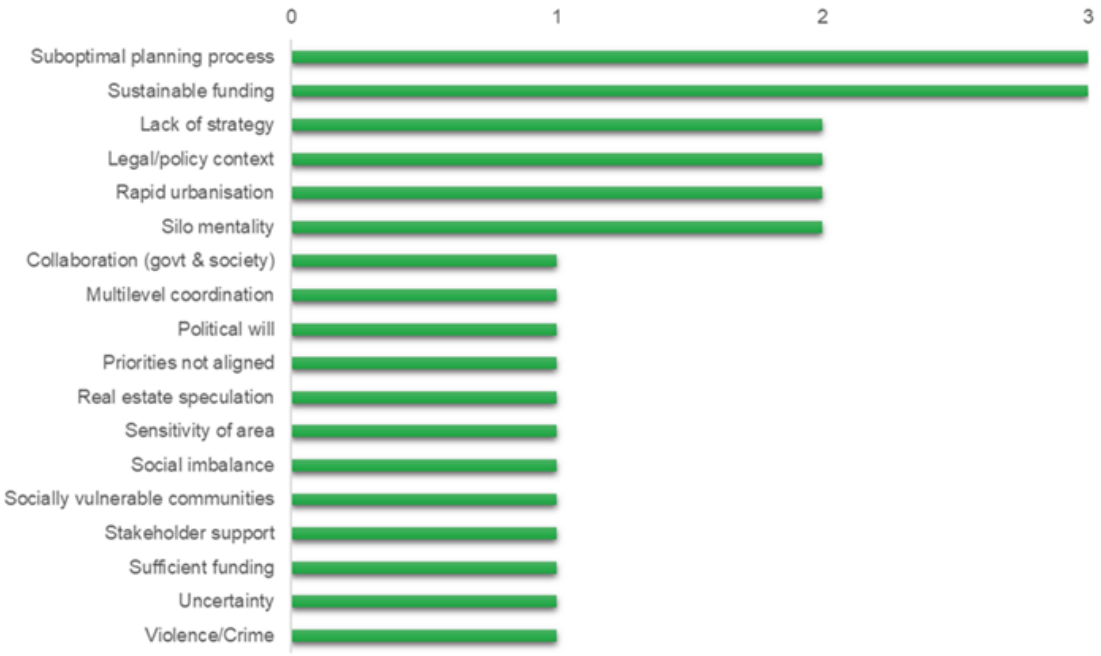


***Figure 61**. What the researchers think the major challenges/barriers are for nature-based solution implementation.*

3.2 Case study briefs for the two South African case studies

3.2.1 Genius of SPACE Project Case Study Brief

Abstract

The Genius of SPACE (Systems for People's Access to a Clean Environment) was a pilot project aimed to apply nature-based solutions (NBS) to treat and manage wastewater and greywater entering the stormwater system, as well as the management of solid waste while empowering local community members, improving living conditions and promoting social upliftment. Langrug, South Africa, is a relatively recently formed and continuously growing informal settlement (slum), where wastewater and solid waste accumulate in the streets due to lack of service provision, sewerage and surface hardening, leading to localised flooding, disease risk and associated health issues. The Stiebeuel River drains the Langrug Catchment (about 4.37 km^2) and enters the Berg River, an important agricultural river for the Western Cape (predominantly winter wheat, vineyards and fruit) entering the sea at the Velddrif Estuary (St Helena Bay), supporting important fisheries. Therefore the eutrophication and pollution of the Berg River causes issues for agriculture downstream, which is particularly important in terms of the stringent growing and import standards of overseas trading partners. The NBS involved installation of 27 greywater disposal points, underground wastewater pipes, permeable paving, grading and pavement construction and 15 tree gardens for water infiltration. Key challenges included complex social and institutional issues, challenges around cooperative governance, communication and integration of efforts between community and local government and budget limitations. Due to these challenges, the NBS pilot was considered a failure by the implementers, and therefore the second phase of the project never realised, which was geared towards generating income and in turn, maintaining service provision. Nevertheless, the community experienced great benefits in terms of ecosystem service provision, social cohesion and health and well-being through this pilot project, and would like it to be reinitiated. Some important lessons can be learnt from this case study to improve success in future applications elsewhere.

Purpose of the case study

The aim of this case study is to evaluate the results of the Genius of SPACE Project as a nature-based solution (NBS) that aims to reduce local and downstream pollution impacts in the informal peri-urban area of Langrug and thus focuses on water quality. The study explores results related to the three dimensions of sustainability, namely, social, economic and environmental and aims to take a systematic perspective on water-related NBS, particularly focussing on resilience, adaptation, complexity, and uncertainty for various peri-urban contexts.

Rather than imposing another "rigid external development model" onto Langrug, the Genius of SPACE project involved local community members in a slow, adaptive process of cooperation, with the aim of designing solutions that the residents of Langrug wanted. Thus, the overreaching aim of the GOS project was environmentally focussed, improving water quality and ecosystem functioning. However, the project aimed to generate several co-benefits including socio-economic opportunities, social development and skills training related to biomimicry and improved health and sanitation. While not all issues were solved, it is said that the Genius of SPACE project laid the foundations to do so, "*assuming the continuation of investment and incremental improvements over time*". This case study

investigates what the major barriers to successful implementation were, and what policy-context would favour successful implementation.

Area characterisation

Location

Province	Western Cape
Municipality	Stellenbosch Municipality
Town	Langrug & Groendal
Area of case study site	4.37 km^2
GPS coordinates	33°53'17.7"S 19°06'10.8"E
Physical context	
Local geography / topography	Informal settlement situated on a mountain slope near to the town of Franschhoek; Cape Fold Group (predominantly sandstone; some shale); Highest elevation: (highest nearby mountain: 1221 m, highest point of township: 302 m); lowest elevation 268 m
Main water courses	Stiebeuel River, a tributary of the Berg River. The Berg River is an important agricultural river in the Western Cape (Ratcliffe *et al.*, 2007), is approximately 285 km long from source to sea, with a basin area of approximately 9 000 km^2. It has its source in the Drakenstein and Franschhoek mountains, south of Franschhoek.
Main soil types	Soil: Glenrosa and/or Mispah forms (other soils may occur); Geology: Talus gravel and colluvial sand on granite of the Stellenbosch Pluton, Cape Granite Suite and quartzite, conglomerate, slate and phyllite of the Franschhoek Formation, Malmesbury Group.
Precipitation (monthly averages as well as climate change projections)	Mean Precipitation (mm) Annual: 903 mm; Monthly Medians: JAN - 17 FEB - 14 MAR - 30 APR - 59 MAY - 123 JUN - 147 JUL - 137 AUG - 116 SEP - 69 OCT - 50 NOV - 25 DEC - 20 The difference in median precipitation between the driest month and the rainiest month is 133 mm. [Data from Cape Farm Mapper vers. 2.2.3]
Temperature range	The climate in Franschhoek is warm and temperate. In winter, there is much more rainfall in Franschhoek than in summer. The Köppen-Geiger climate classification is Csb. The average temperature in Franschhoek is 16.4°C. Minimum 5.6 (July); Max 28.4 (Feb)
Critical infrastructure	The informal settlement (1800 families in 2011) was formed in the 1980s on government land. Community relies on 2 sanitation systems - flush toilets (84% of respondents) and the surrounding vegetation areas/ bush (15.2%). Sanitation services (in the form

	of community toilet blocks) were provided by the City Council, but vandalism means not all are functional. In 2011, there were 0 individual toilet blocks, 91 community toilet blocks (83 functional; 49 people/toilet); 57 water taps (45 functional; avg 72 people per tap)
Other relevant physical factors	Greywater management, solid waste management & stormwater drainage all a concern in this informal settlement; concerns of human health & downstream pollution impacts.

Population	In 2011, ~14500 people in Langrug & Groendal; and 112 on surrounding farms that intersect with the catchment
GPD/capita	N/A
Economic status (i.e. low income, high income)	Very low income
Other relevant socio-economic factors	Working population are mostly seasonal workers from surrounding farms (mostly wine farms). In 2011, 1021 of the household heads indicated that they have electricity meters in their informal houses (referred to as shacks); however, the remaining population depend on other sources of energy such as paraffin, gas, petroleum. The community has experienced flooding disasters and is also affected by crime and drug abuse. *The Langrug settlement is close to the largely wealthy, historical tourist town of Franschhoek, representing a steep gradient of income inequality.*

Physical Context

The Stiebeuel River runs through the informal settlement of Langrug, draining a small subcatchment of approximately 4.37 km^2 (**Figure 62**) before entering the Berg River. The water of the Stiebeuel River is heavily polluted by sewage, litter and domestic wastewater (Cameron, 2018). This is largely due to dysfunctional or inadequate drainage systems in Langrug, but also the low-cost housing area in Groendal, as well as agricultural effluent (Cameron, 2018). Therefore there are significantly high loads of organic pollution and nutrients in the water which has a severely negative impact on water quality and therefore habitat integrity and species diversity of the river (Cameron, 2018). It also has severe implications for human health, especially for incidence of diarrhoea and pneumonia in children who play in the streets and areas contaminated by wastewater, who do not adopt sufficient hygiene practises (Olsson, 2017).

In terms of local geography, the informal settlement is situated on a mountain slope near the town of Franschhoek. The geology is predominantly composed of sandstones and quartzites of the Cape Supergroup, with alluvium in the valley-bottoms (DWAF, 2008), with Glenrosa and/or Mispah soil forms. The highest elevation is around 1221 mamsl, with the township situated at about 260-300 mamsl. The climate in Franschhoek is warm and temperate (average temperature of 16.4°C, with a minimum of 5.6°C and maximum of 28.4°C). The area experiences winter rainfall, with mean annual precipitation of around 903 mm. The difference in median precipitation between the driest month and the wettest month is 133 mm

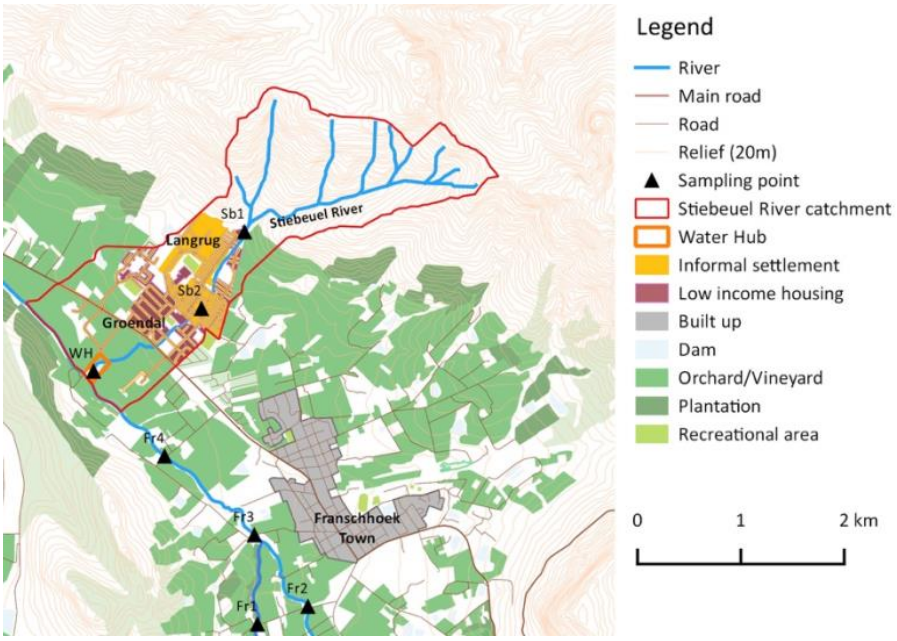


***Figure 62**. The Stiebeuel River at catchment, Franschhoek (from Cameron, 2018).*

Socio-Economic Context

The community of Langrug formed illegally on government land in the 1980s, mainly as a haven for job-seekers from the Eastern Cape looking for opportunities in the wine industry (factories or farming) (Olsson, 2017; Wolfaardt, 2017). Though the squatting was illegal, Stellenbosch Municipality provided basic community sanitation including toilets and taps (communal flush toilets), while others rely on surrounding vegetation. Due to vandalism, not all public ablution facilities are functional. In 2011, there were no individual toilets, 91 community toilet blocks (83 functional; 49 people/toilet); 57 water taps (45 functional; ~72 people per tap) (GGLN, 2013). Therefore greywater management, solid waste management and stormwater drainage are all a major concern in this informal settlement, like many others in South Africa (Armitage *et al.*, 2007). Research from 2007 found that Langrug lacked community structures that can facilitate 'self-help' solutions to greywater management (Armitage *et al.*, 2007). Though research shows that stormwater and sanitation cannot be separated from greywater management, residents appeared less concerned about greywater as a problem compared to other more pressing concerns (Armitage *et al.*, 2007).

In 2012 the population of greater Langrug (including Groendal) was estimated at 13 000 inhabitants, with 10% of them being children under the age of five years (Olsson, 2017). Langrug itself (composed of suburbs: Zwelitsha, Nkanini and Mandela Park) was estimated at between 16-17 years old, all homes are shacks (informal dwellings constructed by hand with available materials), with about 4088 inhabitants, with 41% female-headed households (Stellenbosch Municipality, 2011). Most people have moved to Langrug recently from the Eastern Cape (72%) (ISN, 2011). The economic status of this community is 'very low income' and despite poor water and sanitation services, most households have electricity meters in their homes, while the remaining population rely on paraffin, gas and petroleum. The working population are currently mostly seasonal workers from surrounding farms. The community has experienced flooding disasters (Jiusto & Kenney, 2016) and is affected by crime and drug abuse.

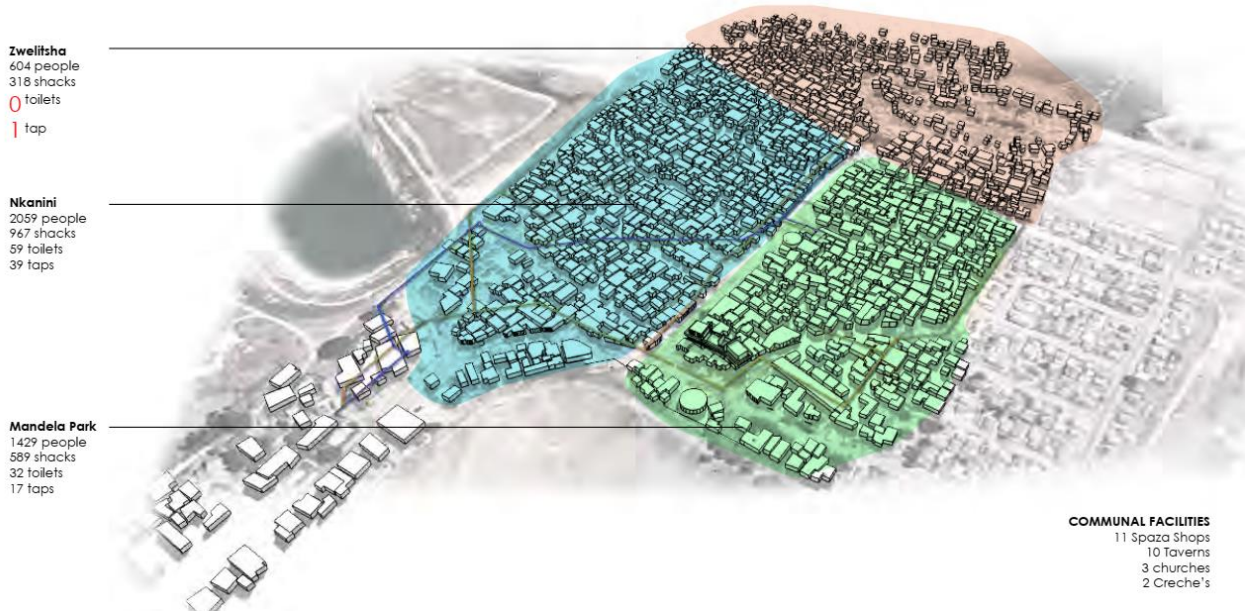


Photo plate: The informal community of Langrug, divided into three suburbs: Zwelitsha, Nkanini and Mandela Park (Source: Genius of SPACE Info Brochure). Since this map was produced (2015), the settlement has expanded up the mountain and into the area around the dam.

Objective of the NBS

The Genius of SPACE project aimed to address water quality and quantity (excess) challenges in the Langrug Community, South Africa.

Rather than imposing another "rigid external development model" onto Langrug, the Genius of SPACE project involved local community members in a slow, adaptive process of cooperation, designing solutions that the residents of Langrug want (Hermanus & Campbell, 2017). While not all issues have been solved, it is said that the Genius of SPACE project has laid the foundations to do so, "*assuming the continuation of investment and incremental improvements over time*" (Hermanus & Campbell, 2017).

Policy and governance context

Both local and regional government have been involved in the Genius of SPACE Project; the Stellenbosch Municipality (local government) and the Department of Environmental and Development Planning (regional – Western Cape Government). In the community, a committee has been established to engage with these stakeholders, called: 'the Langrug Community Projects Committee'. There is a history of governance challenges in this municipality, related to ad hoc, top-down approaches to water-related service provision (Lande & Hendler, 2018). In 2012 a community-led approach was initiated, guided by the 1988 White Paper on Local Government (which includes provision of sustainable services through partnerships between local government, community-based organizations and non-governmental organizations). The partnership consisted of the Stellenbosch Municipality (Informal Settlement Management department; local government) and the Community Organisation Resource Centre (CORC) on behalf of the South African Shack/Slum Dwellers International Alliance. The Langrug Community Projects Committee (LCPC) were the initial intermediary, and the assumption was that community leadership groups would be mobilised and

take over the process, however weak community structures meant that this did not happen. A range of projects were initiated, and the partnership then expanded to include the Worcester Polytechnic Institute and University of Cape Town; and the WaSH-UP Intervention Program – which aims to improve water, sanitation and hygiene in the community – (Muniz, 2013; Olsson, 2017) was conceptualised and completed in 2013 and in 2014 an Innovation Centre in the upper section of Langrug began, motivated by lack of sanitation facilities.

In 2015 the partnership MOU ended. Power relations, community leadership divisions and community ownership issues arose, and the WaSH facility & Innovation Centre were vandalised and misused and eventually demolished by the community (Lande & Hendler, 2018). Another issue cited is that benefits of projects did not necessarily filter down to household level (Lande & Hendler, 2018). In 2015 a new initiative started – the Genius of SPACE project (the focus of this case study) – a collaboration between BiomimicrySA & Informal South (organizations comprising scientists, engineers, architects and innovators that seek designs that use nature-based solutions) and the Western Cape Government's 110% Green Initiative. The Langrug Community Projects Committee was established as the community driver of the project (elected through a general meeting, consisting of community leaders, ward committee members, etc.). Coordination challenges are well-summarised in the following extract: "*Existing local realities of hierarchy, gatekeeping, and powerbrokers have worked against some of the aims of the alliance, which include the building of social capacity*" (Lande & Hendler, 2018). Some of the major challenges related to governance include how to change patterns in decision-making; how to build trust, how to sustain engagement and funding through various project cycles and how to mobilise the community (Armitage *et al.*, 2007; Tàbara *et al.*, 2020; Wolfaardt, 2017). Other research argues that this project has been far from transformative, because it relies on the free or cheap labour of unemployed women for successful implementation (Meiring, 2017). In terms of the benefits, only well-connected women are able to access the resources and opportunities provided by community benefactors, excluding many others (Meiring, 2017). There is very little existing policy support for this type of nature-based solution in South Africa.

Actions

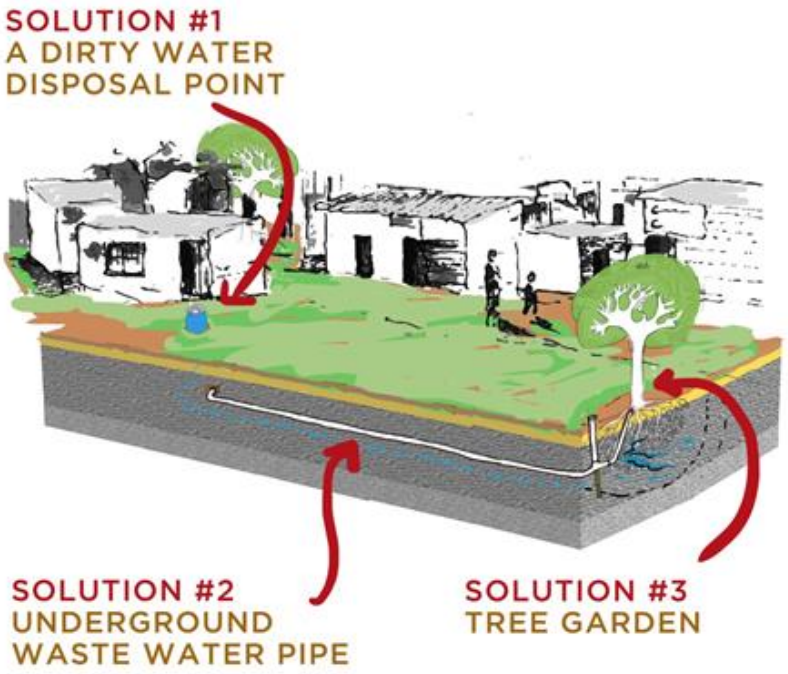


Photo plate: The three solutions proposed by the Genius of SPACE Langrug Community Project, South Africa (Source: Genius of SPACE Info Brochure).

The Genius of SPACE Langrug Community Project proposed a systems-approach to water and waste issues, using methodology that applies nature-based principles to solve water-related challenges. The Genius of SPACE project implemented three solutions in a pilot project: (1) 27 greywater disposal points to manage greywater run-off and the collection and separation of household solid waste in wheelie bins (compostables, recyclables, non-recyclables), (2) underground wastewater pipes to reduce local flood risk and stormwater management (improved road surface with permeable paving, grading and pavement construction) and (3) 15 tree gardens. Eleven fulltime Langrug locals were employed on the Genius of SPACE Project to engage with the community around waste and wastewater disposal, as well as to take care of the nature-based solutions. One of these was appointed 'community liaison officer'. Labour (for the installation of the nature-based solutions) was sourced from within the community.

The Stiebeuel River flows into the Berg River, which is a critical water supply for farmers downstream. The benefits of this nature-based solution were intended to be local (for the community) by reducing flood and disease risk, and improving the community, but also downstream (improved water quality for agriculture). It should be emphasized that the Langrug community is a site of extensive research, with a focus on participatory action methods which emphasise "*participation, collaboration and consensual decision-making with the goal of ensuring long term sustainability of social and technological interventions*" (Carden *et al.*, 2008). However, as suggested by the challenges listed in the section on 'governance context', despite its grass-roots approach, many of the Genius of SPACE initiatives have not continued (DEADP, 2018). Even in 2008, certain risk factors in the community for these types of projects were identified, including: uncertainty about tenure/ownership undermining willingness of inhabitants to take initiative, as well as general unwillingness to take responsibility for service delivery believed to be the municipality's responsibility (Carden *et al.*, 2008).

Potential (or achieved) impacts and benefits

- Reducing littering and improving wastewater disposal through education while the project was running.
- Improving water quality of the Stiebeuel River by improving greywater disposal (i.e. from the surface of the ground into the wetlands and herb and tree gardens), resulting in the filtering of water.
- Creating potential income generating community projects, such as space for vegetables to be grown in the tree gardens and sold within the community.
- Employment opportunities created indirectly through tourism (i.e. guided walks through the informal settlement).
- Education through communication of the clusters on sustainable waste management methods including waste separation, recycling, upcycling, and composting for food gardens.
- Ownership, by the local community, of the nature-based solutions leading to community-based service provision. This is due to a strong bottom-up focus in the project design and implementation.
- The project was environmentally focussed, improving water quality and ecosystem functioning. However, the project aimed to generate several co-benefits including socio-economic opportunities, social development and skills training related to biomimicry and improved health and sanitation. In addition, the project incorporated collective decision-making processes and infrastructure was community-owned and managed.

Results of the case-study interviews: (in brackets, the % refers to the proportion of agreements by implementers or community members; total n=8 and n=23 respectively)

- Connection to nature improved after the NBS (Community: 61%; Implementers: 50%)
- The NBS changed how the community used nature for recreation (Community: 44%; Implementers: 17%)
- The NBS shaped/changed cultural values and practices (Community: 44%; Implementers: 38%)
- The NBS improved community health and wellbeing (Community: 70%. Implementers: 75%)
- Access to water for daily use was not felt to improve by either community members or implementers, however water was felt to become more available for other uses (Community: 78%, e.g. vegetable gardens; Implementers: 38%, e.g. washing machines, trees, businesses)
- The NBS improved gender equality (Community: 65%; Implementers: 0%)
- There was no perceived change in crime following the NBS.
- Improved social cohesion (connectedness, sense of community) (Community: 78%)
- In terms of resulting policy, the Genius of SPACE project assisted implementers in the implementation of another NBS project in Nkanini and Villiersdorp.
- The NBS project played an important role in education: many community members cited being more aware of what happened to wastewater (Community: 83%).
- Implementers felt that the NBS did well in terms of community participation (Implementers: 100%). Community participation was encouraged through the distribution of pamphlets, a community newspaper, people announced meetings in the community with loud-speakers, open days and meetings were held, there was always food and something to drink, door-to-door knocking, with translators, emphasis was placed on building a good understanding of the NBS and questions were encouraged. Implementers wanted as much engagement from the community as possible and a large investment was made into communication.

- Ecosystem services: community perceived increases in provision of most ecosystem services, particularly aesthetic services (65%), food provision (57%), water purification (57%), water regulation (57%) and soil quality maintenance and retention (52%). Implementers particularly agreed that increases were prevalent for aesthetic services (30%), science and education (30%), water purification (26%) and recreation (22%) (**Figure 63**).
- The NBS project directly created new jobs in the community (Community: 78%) for the duration of that project, resulting in an improvement in household income (Community: 61%). Indirectly, jobs were also created through tourism (Implementers: 63%).

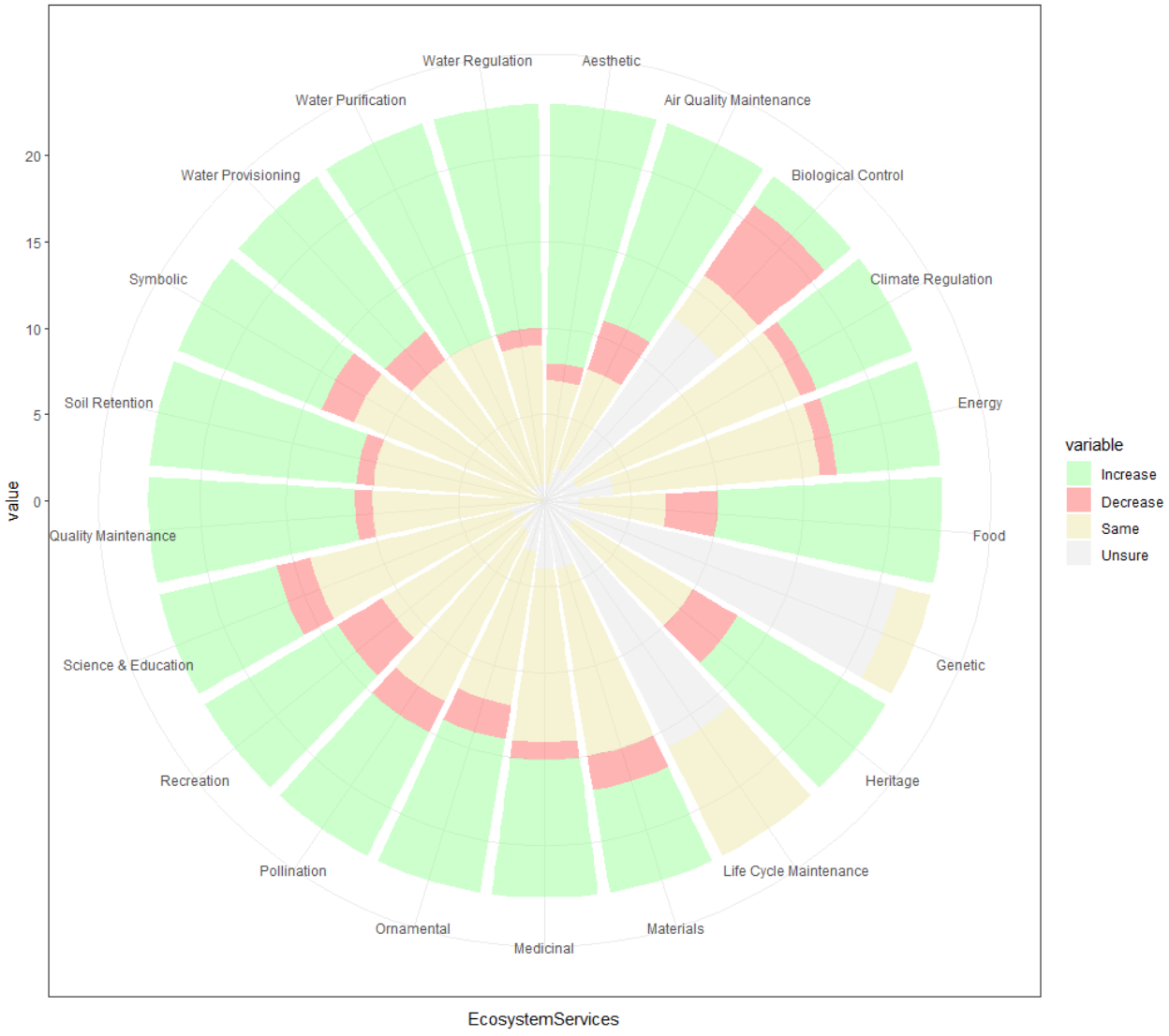


***Figure 63**. The perceived impact of the Genius of SPACE NBS on ecosystem services according to community members (n=23).*

Sustainable development goals addressed

- SDG1 -> Job creation for the impoverished.
- SDG3 -> A decrease in wastewater accumulation above ground
- SGD5 -> Improving gender equality (community perceived an improvement after the NBS)

- SGD6 -> Improved sanitation through the NBS (drainage, improving permeability)
- SGD8 -> Employment opportunities provided through the NBS
- SGD10 -> Improving gender equality (community perceived an improvement after the NBS)
- SDG11 -> Installing green infrastructure
- SDG14 -> water quality improvements (less litter and sewage entering the river).

Lessons learnt

- Challenges: The greatest challenges for implementation identified by implementers were (in order of importance): the social imbalances, sustainable funding, collaboration (government and society), stakeholder support, rapid urbanisation, and sufficient funding.

Ecological

N/A

Social/governance

- Project management: In terms of how well the project was run, the community rated it as 3.5/5 (1 = very poor; 5 = very good). Implementers felt that the project was well run, it started very well but commitment fizzled out, because the project failed to consider risks and how to mitigate them, and also that it failed to budget for 80% engagement, 20% work (in community work). Overall implementers felt that there was sufficient expertise, knowledge and skills of actors (75%), but one felt that initially this was not the case, and that it was a steep learning curve for all involved.
- Governance: Implementers felt that specific personal values and attributes facilitated the NBS process (75%), for example: being engaging, having empathy and giving support, willingness to be involved in necessary conflict, and to be part of a process. This project implemented a co-create, co-design approach. A lot of investment went into community participation and understanding and ultimately involvement. This required a level of resilience and commitment. The ability to speak to and negotiate with people who are directly affected by the NBS and build trust. The importance of having a champion implementer was raised. The engineers working on the NBS were suggested to have taken a traditional silo approach, and did not engage with the vision of the project.
- Governance: This NBS was an interdisciplinary project (Implementers: 88%); there was a lot of collaboration, especially between the implementers and community members. Although, collaboration was often lacking regarding the municipality. Only one implementer felt that this was not the case (was a bit of silo's, not enough public participation meetings. Would have worked a lot better if, e.g., surrounding farmers were involved).
- Power struggles were present in the community but were not thought to be significant by the implementers (i.e. certain individuals with agendas or trying to reach a leadership position, ego's, hidden agendas) (Implementers: 38%).
- There was a lot of effort to incorporate cultural/societal values sufficiently (Implementers: 75%). Cultural/societal values were mainly incorporated via the planting elements and placement of infrastructure.
- Some conflict/tension among actors was noted (Implementers: 50%). There was quite a bit of tension with the community at times in terms of work ethics, contracting, payment. Also level of theft, vandalism and loss of materials. Limited buy-in from municipality (their

property) and breakdown in communication at times which led to difficult situations when it came to implementing.

Economic

- Unsustainable funding was the main issue for the project (Implementers: 88%). The second phase of the project never received funding, which is the phase that was supposed to generate income for the community. Government led funding which is very short-term and cyclical and it is punitive, if incapable of spending budget allocated within certain time frame, the opportunity to get a similar budget diminishes. To sustain that investment with various challenges faced, towards the end of project became difficult to plot way forward.
- Community recommendations: Continue with the project and assist other sections of the town as well, Community members involved would not listen to advice/recommendations, Only people from the pilot area were employed in the project, Vandalism led to failure of the pilot project, Train the right people, better communication and understanding and build a trustworthy network, Work together with the community and employ everyone, Assist all sections with water, The community was not consulted initially, budget could have been better used, More taps & cleaner town needed, More job opportunities desired, Clean drains & environment desired, Our voices were not heard, Desire to install toilets and sewerage, Partner with municipality to leverage more funds, Could have implemented new systems and taught youth, They did not work together.

Transferability of results

The results of this case study are most useful to practitioners (locally or globally) in that they shed light on the major barriers to successful implementation of green infrastructure types of nature-based solutions in peri-urban areas, and what policy-context would favour successful implementation.

Recommendations:

- Future projects should explicitly consider potential risks and how to mitigate them.
- Future projects should apportion their budget for 80% community/stakeholder engagement, 20% for the physical NBS implementation work. Many projects may not budget for the community/stakeholder, and this engagement can determine the project success.

Photos of the NBS case study

Photo 1: The Stiebeuel River flowing through the informal settlement of Langrug that is encroaching up the mountain.

Photo 2: Wastewater flowing down the streets of Langrug, Franschhoek.

Photo 3: Installed greywater disposal point (blue drum).

Photo 4: Constructed permeable paving between Block S and T.

Photos by Dandi Kritzinger (March 2021)

3.2.2 Dwars River Alien Tree Clearing Project Case Study Brief

Abstract

The Wildlands Trust has been coordinating several riparian rehabilitation projects along the Dwars River, a tributary of the Berg River in the Western Cape, South Africa, since August 2018. The Dwars River is heavily transformed, with landcover converted to predominantly agriculture over the past 300 years (mainly viticulture and fruit), an inter-basin transfer out of the catchment affecting the hydrological regime, and these disturbances *inter alia* resulting in infestation of the riparian zone by invasive alien trees and weeds. These invasive alien trees consume high volumes of water, reducing water supply, increasing fire risk, and negatively impacting biodiversity. The nature based solution implemented by Wildlands Trust involves three approaches: (1) the clearing of invasive alien trees, shrubs and weeds from the riparian zone (initially through logging operations, with follow-up clearing), (2) active rehabilitation of the riparian zone, through the planting of indigenous tree seedlings, and (3) engaging the community through creating employment opportunities in the rehabilitation programme, as well as a recycling and native tree growing programme, aimed to keep the river clean, in exchange for rewards (e.g. bicycles). This nature-based solution takes a socio-ecological systems approach and aims to improve hydrological flows (increase water availability) as well as engage the community, and indirectly – if implemented at scale – may improve water quality (dilution effects). The scale of the implementation is currently relatively small (small sections/strips of riparian zone along the river) and therefore the benefits of these interventions are mainly local and difficult to quantify. The nature-based solution appears to have had a very positive reception by the community, and good communication is cited as key in having achieved this. Many community members perceive improvements to nature (improvements in ecosystem services), which are experienced directly in terms of recreational benefits, improvements to aesthetics, and general well-being, social cohesion and nature-connectedness. Any benefits in terms of augmented water supply or quality, though perhaps small due to the scale of the work, would be beneficial to downstream farmers who rely on the Dwars and/or downstream Berg River for irrigation.

Purpose of the case study

The aim of this case study is to evaluate the results of the Wildlands Trust invasive alien clearing and riparian rehabilitation of the Dwars River as a nature-based solution that aims to increase water quantity downstream. The study explores results in terms of all three dimensions of sustainability, namely, social, economic and environmental.

Area characterisation

Location

Country	South Africa
Province	Western Cape
Municipality	Stellenbosch Municipality
Town	4 towns - Kylemore, Johannesdal, Pniel, Lanquedoc
GPS coordinates	33°53'48.1"S 18°57'32.5"E
Physical context	
Surface	63.87 km^2

Local geography / topography	Formal (small towns) and informal settlements situated in a mountain valley near to the Dwarsriver; Cape Fold Group (predominantly sandstone); Highest elevation: (highest within the community 333 m; highest local mountain peak: 1449 m); lowest elevation 266 m
Main water courses	Dwarsriver, a tributary of the Berg River. The Berg River is approximately 285 km long from source to sea, with a basin area of approximately 9 000 km^2. It has its source in the Drakenstein and Franschhoek mountains, south of Franschhoek.
Main soil types	Soil: Plinthic catena: dystrophic and/or mesotrophic; red soils not widespread, upland duplex and margalitic soils rare; Geology: Mainly gritty sand, scree and alluvium covering granite of the Stellenbosch Pluton, Cape Granite Suite.
Temperature	The monthly distribution of average daily maximum temperatures (centre chart below) shows that the average midday temperatures for Kylemore range from 14.8°C in July to 25.3°C in February. The region is the coldest during July when the mercury drops to 5.8°C on average during the night. So range 25.3-5.8
Precipitation (monthly averages as well as climate change projections)	Mean Precipitation (mm) Annual: 1202; Monthly Medians: JAN - 22 FEB - 16 MAR - 27 APR - 71 MAY - 138 JUN - 154 JUL - 175 AUG - 157 SEP - 91 OCT - 57 NOV - 36 DEC - 27 The difference in median precipitation between the driest month and the rainiest month is 159 mm. [Data from Cape Farm Mapper ver 2.2.3]
Critical infrastructure	Pniel Wastewater Treatment needing urgent upgrade & extension - on the river bank (Wildlands monitors overflows & reports to municipality; planned mini SASS -Stream Assessment Scoring System- reporting); water extracted for Boschendal (divider sluice); planned extended bridge construction over river near Lanquedoc. Farms use water for irrigation (even dam a tributary - with Black Alder invasion source)
Other relevant physical factors	Greywater management, solid waste management & stormwater drainage all a concern; concerns of human health & downstream pollution impacts.
Population	In 2011 there were around 1 975 people living in Pniel, 4 328 in Kylemore, and 4 289 in Lanquedoc (South African census 2011).
GPD/capita	No info.

Economic status (i.e. low income, high income)	Low-income communities contrasting with rich farm/land-owners.
Other relevant socio-economic factors	Working population in the small towns are mostly seasonal workers from surrounding farms (mostly wine farms). The community is affected by crime and drug abuse.

Physical Context

The steep and rugged mountains surrounding the Dwars River are predominantly sandstone and quartzite, reaching up to over 1500 m above sea level (Simonsberg is at 1399 mamsl), whereas the wide valleys are highly arable (around 300 mamsl), dominated by decomposed granite and shale soils with good drainage (Forsyth, Le Maitre, & Lötter, 2016; Forsyth, Le Maitre, Smith, *et al.*, 2016). The Dwars River (or Dwarsrivier) is a tributary of the Berg River. The geology of the Dwars river catchment is similar to that of the Upper Berg but also includes gritty sand, scree and alluvium covering granite of the Stellenbosch Pluton, with Cape Granite Suite in the valley. Soils are mainly dystrophic and/or mesotrophic. The mean annual precipitation of the catchment is around 1202 mm, most of this received in the winter. The difference in median precipitation between the driest month and the wettest month is 159 mm. The Dwarsrivier valley (63.87 km^2) is an important agricultural area, predominantly for viticulture and fruit farming, forming part of the Cape Winelands. Many of the farmers in the area are part of the Simonsberg Conservancy, which is the implementer for some of the alien clearing using Working for Water funding (Natural Resource Management, Department of Environmental Affairs), and some landowners are World Wide Fund for Nature (WWF) Champion Farmers (a biodiversity and water stewardship programme). There are many small towns in the Dwarsrivier valley, including Pniel, Kylemore, Johannesdal, and Lanquedoc (Forsyth, Le Maitre, & Lötter, 2016; Forsyth, Le Maitre, Smith, *et al.*, 2016).

One of the major issues in the Dwars River catchment is invasive alien trees, which are high water users. In the high-lying areas, pines are the major invasives (*Pinus pinaster* and *P. radiata*), and in the rest of the catchment, wattles (*Acacia mearnsii, A. spp.*) and gums (*Eucalyptus camadulensis, E. spp.*) are dominant, and major riparian invaders include Black Alder (*Alnus glutinosa*), poplars Oaks, and Elms (Forsyth, Le Maitre, & Lötter, 2016; Forsyth, Le Maitre, Smith, *et al.*, 2016). Failing infrastructure (Pniel Wastewater Treatment Works) is also an issue, leading to sewage flowing into the rivers, as indicated by the high faecal coliforms and electrical conductivity entering the river through a dysfunctional sewage system (**Figure 64**, **Table 9**, source: Wildlands Trust). This is a health threat to those using the river recreationally (often children) as well as to agricultural produce that is irrigated by river water downstream, and may impact international certification. The river plays a strong buffering role for this sewage, probably largely through dilution effects (**Table 9**). Besides water security, invasive alien trees pose a major fire risk, through increased fuel loads. Fires are a natural part of this ecosystem, and are common in summer, between December and March (Forsyth, Le Maitre, Smith, *et al.*, 2016). These fires perpetuated the invasive alien tree problem through stimulating the germination of large numbers of pine, gum and wattle seedlings (Forsyth, Le Maitre, & Lötter, 2016; Forsyth, Le Maitre, Smith, *et al.*, 2016), all of which are fire-adapted, posing a risk to bordering infrastructure.

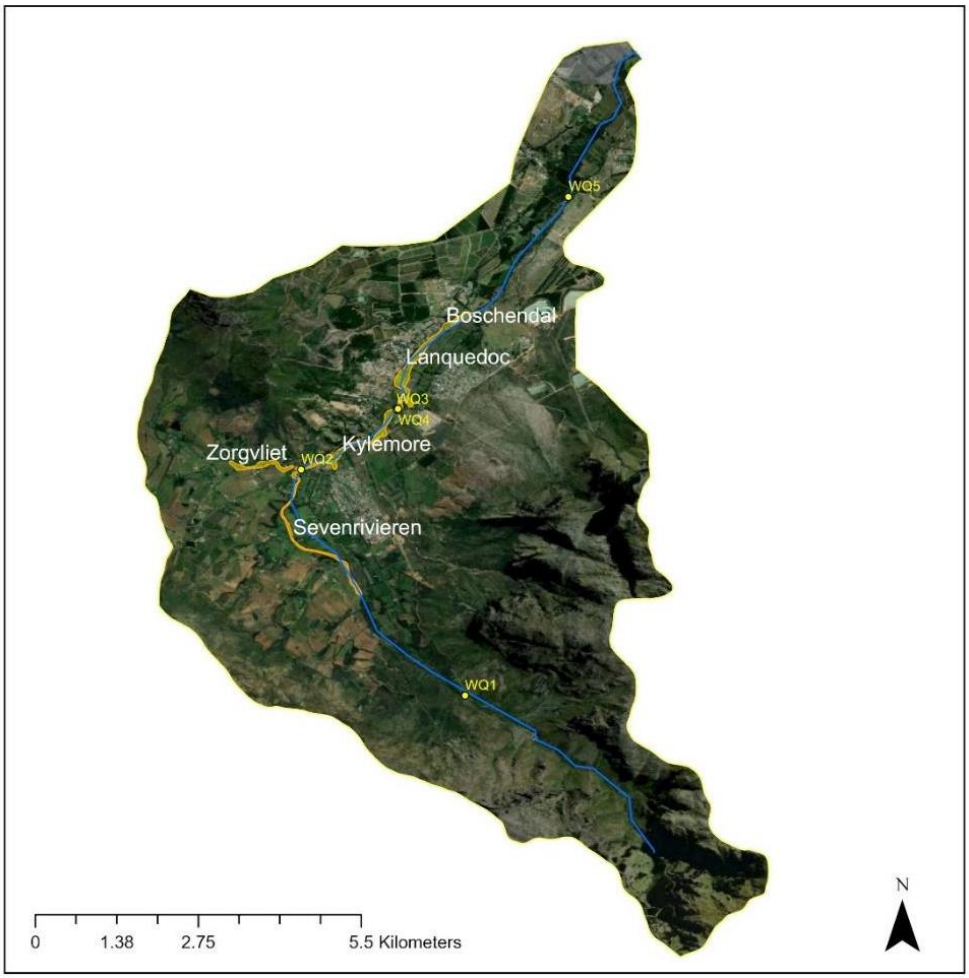


***Figure 64**. Rehabilitation sites for the Wildlands Trust along the Dwars River (orange polygons and labels in white) and water quality sampling locations in yellow.*

***Table 9**. Water quality sampling in September 2018 by the Wildlands Trust along the Dwars River (see **Figure 64** for sampling locations). WQ2 (shaded) results show the influx of sewage.*

Site	Electrical Conductivity (mS/m)	NO3-N (mg/l)	COD (mg/l)	Suspended solids (mg/l)	Faecal Coliforms (CFU/100 ml)
WQ1	5	<0.36	8	0	2
WQ2	40	1.18	96	37	>2420
WQ3	11	1.28	8	0	109
WQ4	10	<0.36	7	0	38
WQ5	11	1.02	7	0	142

Socio-Economic Context

The Dwars River Valley has its recent roots in the colonisation of the Cape and has ties to slavery and oppression. As a result, the current socio-economic context is highly complex, with large inequalities between wealthy landowners (in some cases luxury properties) and people residing in the local towns (Van der Waal, 2005). The communities are affected by high crime levels and drug abuse (Methner & Midgley, 2020). The valley may be classified as peri-urban given the fast paced, and highly contested, spatial transformation currently taking place (Van der Waal, 2005). New forms of land-use have led to conflict between farm workers and developers, especially where linked to heritage conservation (Van

der Waal, 2005). In terms of population, in 2011 there were around 1 975 people living in Pniel, 4 328 in Kylemore, and 4 289 in Lanquedoc (South African census 2011). In terms of the economic status of the catchment, there is a very high contrast, with rich farm owners adjacent to low-income communities. Much of the working population in the small towns are seasonal, working on surrounding farms (Methner & Midgley, 2020).

Objective of the NBS

The Wildlands Trust implements invasive alien clearing and riparian rehabilitation of the Dwars River using a socio-ecological systems approach as a nature-based solution that aims to increase water quantity downstream (addresses water shortage).

Policy and governance context

There are three levels of governance involved in the nature-based solution (riparian rehabilitation) in the Dwarsriver, including national, some regional involvement, and to a lesser extent, local. National governance is primarily through providing funding for the riparian rehabilitation, funding is from National Treasury and channelled through the Department of Environment, Forestry and Fisheries (Midgley *et al.*, 2020). Non-Governmental Organisations administer the funds and coordinate the work, and in the Dwars river these include the Wildlands Trust, and the Simonsberg Conservancy. There is some regional government interest in the rehabilitation work along the Dwars River, primarily that of the Department of Environmental and Development Planning (Western Cape Government). In terms of local governance, the Stellenbosch Municipality is involved, mainly through their role in wastewater treatment and maintenance of local parks close to the river. There is some cross-pollination between tiers of government, for example the Department of Environment Affairs, Forestry and Fisheries specify catchment-based units of importance, and interventions are to be based on these specifications. National funding is in tandem with provincial planning, especially in the Natural Resource Management Programme; previously Working for Water, and all its affiliate groupings Working for Wetlands, Forests, etc.

Some of the major governance-related challenges include the lack of transdisciplinary engagement and operating in silos (Rebelo & Methner, 2019). Another major challenge includes the building of trust (Rebelo & Methner, 2019), within government tiers, departments and with communities, especially where there are diverse interests and agendas. How to sustain engagement and funding through various project cycles; how to mobilise the community (stakeholder engagement) and change patterns in decision-making are other major challenges that need to be addressed. Other stakeholders involved in the nature-based solutions in the Dwars River include community stakeholders (community committee, local residents, landowners such as Old Bethlehem, Boschendal, Alleé Bleué and Solms Delta), other non-governmental or non-profit organisations, recreational groups (e.g. Simonsberg Conservancy, Banhoek Conservancy, RANYAKA, Stellenbosch Trail Fund), other government departments (e.g. Department of Agriculture – LandCare) and universities. The potential for opportunities for socio-economic development and tourism opportunities is a leverage point that may bring this diverse group of stakeholders together to engage.

Actions

The Wildlands Trust has been coordinating several riparian rehabilitation projects along the Dwars River since August 2018 (**Figure 64**). Funding is provided through the Natural Resource Management programme of the National Government Department of Environment, Forestry and Fisheries. This riparian rehabilitation involves three approaches and takes place either on municipal or privately owned land. Firstly, the clearing of invasive alien trees, shrubs and weeds from the riparian zone. The trees are cleared initially through logging operations, whereas subsequent follow-up clearing may involve foliar spray of herbicides, cutting and spraying of herbicides or hand-pulling, depending on the target invasive alien species. Secondly, there is active rehabilitation of the riparian zone, through the planting of indigenous tree seedlings. Thirdly, there is an attempt to engage the community through creating employment opportunities in the rehabilitation programme, as well as a recycling programme, aimed at keeping the river clean, and Treepreneurs Project. The Treepreneurs Project encourages and empowers school learners to grow trees and sell the seedlings to the project seven to eight months later for a reward (e.g. a bicycle). Environmental outreach days were held at schools (with tree-planting initiatives). The project informed the community, and asked for input on how to involve the community. Therefore this project takes a socio-ecological systems approach and aims to both improve hydrological flows (increase water availability), as well as engage the community (Adams *et al.*, 2020). The scale of the implementation is relatively small, and there is a gap in South Africa in understanding how to upscale, or finance these nature-based solutions at scale (Midgley *et al.*, 2020). Therefore the benefits of these interventions are anticipated to be mainly local, however any benefits in terms of augmented water supply or quality, would be beneficial to downstream farmers who rely on the Berg River for irrigation.

Potential (or achieved) impacts and benefits

Results of the case-study interviews: (in brackets '%' refers to the number of agreements; total sample sizes: n=20 and n=3 for the community and implementers respectively)

- Connection to nature improved after the NBS (Community: 80%; Implementers: 0%)
- The NBS changed how the community used nature for recreation (Community: 70%; Implementers: 66%)
- The NBS shaped/changed cultural values and practices (Community: 50%; Implementers: 0%)
- The NBS improved community health and wellbeing (Community: 75%; Implementers: 33%)
- The community perceived that water supply (riverflow) has increased, and water become more available for other uses (for example: gardens and farms) (Community: 40%)
- Reduced crime following the NBS (Community: 55%)
- Improved social cohesion (connectedness, sense of community) (Community: 65%)
- The NBS created new jobs in the community (Community: 65%, Implementers: 100%); community members were employed in the NBS work, and there were also jobs created indirectly, e.g. through recycling, a gate keeper.
- There was an improvement of income for 9/10 (90%) of the workers interviewed in relation to their previous employment situation.
- Additional economic benefits of the alien tree clearing were cited by implementers to be reduced fire risk (66%).
- Ecosystem services: community mostly perceived increases in provision of ecosystem services, particularly aesthetic services (85%), heritage (75%), soil quality maintenance (75%), energy provision (75%) and recreation (70%) (**Figure 65**). Implementers agree that there were

improvements to water provisioning, provision of materials, energy, ornamental services, as well as water purification, regulation and life cycle maintenance (all 100%).

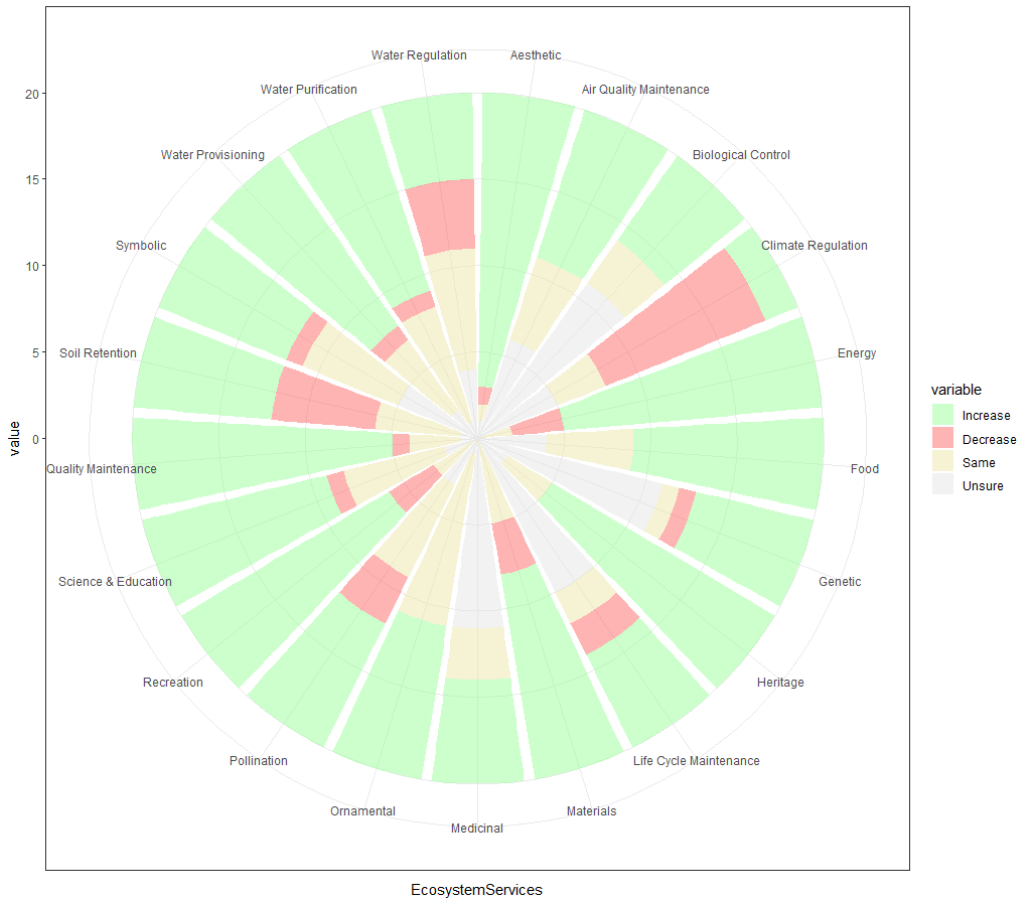


***Figure 65**. The perceived impact of the Dwars River NBS on ecosystem services according to community members (n=20).*

Sustainable development goals addressed

- SDG1 -> Job creation for the impoverished.
- SDG3 -> Dilution effects of sewage (more water available due to lower water use of indigenous vegetation), resulting in positive health impacts for those using the water for irrigation, or recreation.
- SGD6 -> Improvements in water quality through the NBS (dilution effects)
- SGD8 -> Employment opportunities provided through the NBS
- SGD10 -> Improved equality (income provided for workers through the NBS)
- SDG11 -> Improvement of the sustainable use of water within these communities (and peri-urban areas)
- SDG12 -> Improved quality and quantity of water for agricultural irrigation (responsible consumption improved through removal of invasive alien trees, but also responsible production -less impact of sewage)
- SDG14 -> Water quality improvements (dilution effects) and associated impacts on aquatic life.

- SDG15 -> Improvements to the riparian ecosystem (improved biodiversity following alien tree removal, of plants and also animals)

Lessons learnt

- Challenges: The greatest challenges for implementation identified by implementers were (in order of importance): Sustainable funding, silo-mentality, sufficient funding, multi-level collaboration, socially vulnerable communities.

Ecological

- Due to social and governance barriers, implementation often had to take place in an ecologically inviable manner (e.g. tackling dense infestations of invasive alien trees first, and the lower reaches of the river) risks compromising project success in the long term. This is especially in the context of extremely insecure funding for the medium to long-term and the unreliability of these funds, where having secure funding for follow-ups in this area, at least for the next 30 years, is essential.

Social/Governance

- The involvement of a champion in implementing the NBS is key.
- There are significant barriers to undertaking an ecologically strategic approach in the case of this NBS in the Dwars. These are cited as: (1) the absence of a platform to engage these landowners (privately owned land vs community trust land which they opted to work on), (2) insufficient funding to seek out and engage private landowners, or establish such platforms, (3) private landowners are difficult to find, communicate with, are often not willing to grant access to their land by workers, and have high turn-over, (4) in some cases, the invasive alien trees hide illegal activities like water abstraction, adding an additional challenge in working with the landowners involved in these practices. Recommendations: (1) The major NBS funder (DEA-NRM) should allow more budget for engagement, (2) perhaps there is the need to make more use of directives on noncompliant landowners.
- Tension was occasionally felt between implementers and community, or implementers and workers. There was an attempt to encourage community buy-in, via a trading project (i.e. litter collection/tree-planting for bicycles).
- The community felt that employment from the local community could be increased, and more people involved. Better communication was also mentioned: that the public should be notified about plans. However, many community members also felt that communication about the project was good. Better community engagement upfront was proposed (a multi-phased approach), as well as improved education and awareness around invasive alien trees.
- This catchment is complex, for example the sewage works discharging into the river is a major issue. There are some people who drink water from the river, and children play in it, and this water is not safe. It has also affected livelihoods: a local rosemary farm tried to sell their produce, but could not, due to this contamination. The value of the river is not recognized and funding to maintain and restore ecological infrastructure should be improved.
- Emerging from the results of perceptions in changes of ecosystem service provision is the strong need for ecological education. There appears to be general misconceptions about the value of trees, which do not apply in the case of alien trees in fynbos ecosystems, which may be being propagated in South African communities by the international discourse and aggressive marketing/publicity on tree planting (i.e. Bonn initiative). People hold two major misconceptions relating to fynbos ecosystems identified through this research: (1) that alien

trees are valuable in soil retention and erosion prevention, and (2) that alien trees combat global warming by sequestering carbon. Many invasive alien trees outcompete indigenous flora, and due to competitive advantage and lack of pests, form closed canopy systems which result in little to no vegetative ground cover. The lack of cover results in soil loss and erosion. People perceive trees to be "holding onto the soil" because their roots become exposed through erosion, creating the impression that the trees hold back the soil, when the opposite is the case. In terms of the carbon sequestration ability of alien trees in fire-prone ecosystems, due to regular fires burning above ground biomass, any sequestration will need to be taking place below ground. The native fynbos, with its resprouters and rich geophytes and bulbs, are thought to store far more carbon below ground than invasive alien trees, as well as trap more carbon in soils due to better ground cover of vegetation (less erosion), as well as support more healthy microbial communities, which are an important factor in carbon sequestration. Education on these points is essential to improve local appreciation of native flora and their role in regulating the environment.

Economic

- Unsustainable funding is a huge challenge, resulting in not being able to pay workers or work to schedule, compromising the project (and leading to loss of workers).

Transferability of results

Some of the major challenges has been the silo mentality in government as well as multi-level collaboration with both government and landowners. This affects where in the landscape the nature-based solution is able to be implemented, with consequences for riparian rehabilitation success. For example, ecological theory and experience dictate that catchments should be cleared of invasive alien vegetation from the top-down, and that sparse invasions should be tackled first, and dense infestations only tackled if sustainable funding is available and secured to continue the follow-up clearing in the long-term (Holmes *et al.*, 2020). In the case of the Dwars, this ecologically-viable alien clearing approach has not been able to be followed, due to the complexity of land-ownership and multi-level collaboration dynamics, lack of funding for engagement, challenges engaging with multiple private land-owners, and noncompliant landowners. This is an important lesson for planning and communication in future nature-based solution projects of this type.

Photos of the NBS case study

(Photos credits: (1-2) Lydia van Rooyen and (3-4) Alanna Rebelo)

Photo 1: Dense infestations of Black Wattle (Acacia mearnsii), Black Alder and poplars cover the disturbed and degraded banks of the Dwars River, Western Cape, South Africa.

Photo 2: Working for Water teams (under the implementing agent: Wildlands Trust) clear foliage following logging operations of mature alien trees in the riparian zone.

Photo 3: Working for Water teams in operation. Working for Water is part of the Expanded Public Works Programme (EPWP) funded by National Treasury to create jobs).

Photo 4: The Dwars River is located in the mountainous parts of the Upper Berg catchment and has been intensively farmed for almost 400 years, and is currently an important agricultural catchment, particularly for viticulture. Landcover is therefore highly transformed, and the hydrology of the system is altered by an inter-basin transfer, and there is much abstraction from the river, some legal and some illegal - like this sluice pictured here.

3.3 Photo stories for the South African case studies

3.3.1 Genius of SPACE Project Photo Story

Green Infrastructure as a Nature-based Solution: The case of the Genius of SPACE Project, Langrug, South Africa

The informal settlement of Langrug in South Africa, with houses made of corrugated iron. Lack of spatial planning, sanitation and sewerage is evident (Photo credit: Cape Winelands Biosphere Reserve).

Introduction

The Genius of SPACE (Systems for People's Access to a Clean Environment) project in Langrug, South Africa aimed to develop and implement an innovative solution to water pollution based on biomimicry principles. The Genius of SPACE project was a pilot project on greywater treatment (i.e. kitchen, laundry, and wash water), stormwater management systems and solid waste management. The Nature-based Solution comprises both "grey" infrastructure such as greywater disposal points, an improved road surface with permeable paving (stormwater management), wheelie bins (collection and separation of household solid waste), as well as "green" infrastructure also known as ecological infrastructure, namely, tree gardens (water filtering sites) and a vertical wetland (a planted filter bed that is drained at the bottom).

This Nature-based Solution specifically tackles the issue of water quality, by attempting to improve infiltration and local wastewater treatment so that the water entering the river downstream of the settlement is of higher quality. By virtue of improving infiltration, this project also addresses the issue of water quantity in terms of water excess, by assisting with absorbing runoff during high rainfall events, reducing local-scale flooding. The scale of this implementation was local since it was a pilot study, so benefits are expected to be local. Many community members perceived improvements to nature (improvements in ecosystem services), which are experienced directly in terms of recreational benefits, improvements to aesthetics, science and education, and general health and well-being, social cohesion and nature-connectedness. Any benefits in terms of augmented water supply or quality, though perhaps small due to the scale of the work, would be beneficial to downstream farmers who rely on the Berg River for irrigation and need high quality for international certification of heir produce. The aim of this photo story is to highlight the value of green infrastructure in informal settlements as a nature-based solution through a series of photos, demonstrating both the implementation, but also the benefits to society.

The ecological, social, economic and political context

The Langrug settlement formed alongside and upslope of the Stiebeuel River, which is a small tributary of the greater Berg River, one of the most economically important rivers for the Western Cape of South Africa. The climate of the region is Mediterranean, and the native vegetation is fire-prone fynbos, a biodiverse shrubland.

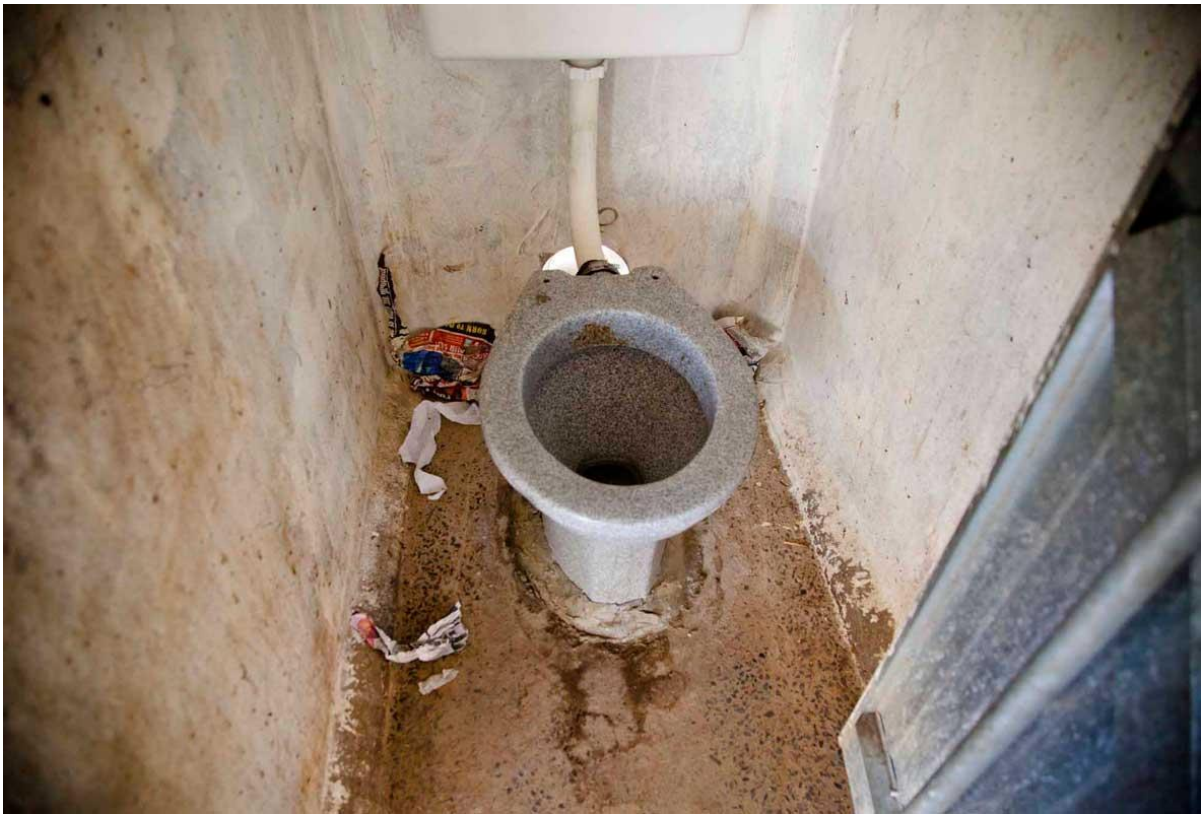
A drone image showing the location of Langrug in the Boland Mountains of the Fynbos Biome, Western Cape, South Africa (Photo credit: Cape Winelands Biosphere Reserve).

The informal settlement is situated within a small subcatchment, near the prosperous tourist town of Franschhoek. The Stiebeuel river – a tributary of the Berg River – originates in this catchment and it runs through the low-income settlement of Langrug and other towns, until its confluence with the Berg River. The water of the Stiebeuel River is heavily polluted by sewage, domestic wastewater and litter. This is mainly due to dysfunctional and inadequate drainage systems in Langrug, although, also a result of agricultural runoff and low-cost housing in the area. The settlement is growing, mainly with immigration for seasonal farm labour, expanding up the slopes of the mountain, making it especially challenging for municipalities to construct drainage systems or install any type of infrastructure. The Stiebeuel River has a persistently high *E.coli* bacterium count, constituting health issues both for residents and farmers downstream using the river.

Large amounts of wastewater (sewage and greywater) and litter accumulate in the streets which pose serious health risks to the community, allowing disease to fester and spread. Additionally, contaminated water, as well as odour and visual pollution have a major impact on the living conditions of residents. They have reported that children were getting falling ill from playing in the dirty water. The settlement faces exceptionally high unemployment rates and social vulnerability, and crime and drug abuse are rife.

Open gullies that channel greywater outflow, polluted with litter, and pooling in some places, Franschhoek (Photo credit: FLOW website).

Although the settlement formed by illegal squatters, basic sanitation needs such as taps, and toilets were provided by the municipality years ago. These basic services are limited in the settlement and local authorities cannot keep up with maintenance and vandalism and the increasing population. In Langrug there are 91 community block toilets of which 83 are functional, suggesting 49 people per toilet. Water taps are limited to 72 people per tap as merely 45 are functional.



Vandalized communal toilet illustrating poor sanitation services, Langrug (Photo credit: FLOW website).

Technical details of the Nature-based Solution

For the Nature-based Solution, 27 greywater disposal points were installed, as well as underground wastewater pipes, permeable paving, grading and pavement construction. In addition, services such as the collection and separation of household solid waste in wheelie bins were established and 15 tree gardens were planted. People from the community were involved in the design and implementation phases and labour was recruited from the community to do the work. The greywater disposal points (blue, round drums) were interconnected via underground piping to tree gardens and the wetland, with a final outflow connection to the municipal sewer. The project included final site preparation, installation and subsequent training for maintenance and operation of both the water and waste prototypes. These low-tech, shared-ownership, and easily maintained solutions were intended to help address the key challenges within the community.

The improved road surface in Langrug, with permeable paving and tree gardens as part of the Genius of SPACE Nature-based Solution, South Africa (Photo Credit: Genius of SPACE Langrug Community Project)

Implementation of the Nature-based Solution

Collaboration between service providers who facilitated the process, and community members involved in the design and implementation of the intervention, was a key part of project implementation. The idea was for the project to proceed in a bottom-up manner, but in practice was a combination of top-down and bottom-up. Stakeholders from various sectors were included in the process and the team provided technical experience covering informal settlement upgrading, urban design, conventional and wastewater treatment technologies, civil and structural engineering. Additionally, stakeholders had experience in Collective Decision Making, Public Participation, and Stakeholder Engagement. During the project, the Langrug Community Project Committee was formed as a representation of the community. There was a strong sense of capacity building and skills transfer in both directions, from the implementers to the community, but also vice versa.

A functional greywater disposal point (blue plastic structure) between informal houses in Langrug, South Africa (Photo credit: Alanna Rebelo).

Challenges

The pilot project faced many challenges, and as a result was not upscaled within the community. Social imbalances, rapid urbanisation, crime and vandalism were listed by community members and implementers alike to be key challenges faced by the project. In addition, despite the best intentions, the community felt that communication and collaboration was poor, and this may be as a result of factions forming within the community, resulting in certain networks benefitting while others were excluded. This poor communication was thought to be underpinned by weak relationships and lack of trust between government and society. This translated into a lack of stakeholder support, which was a challenge. Despite this, many community members valued the project itself, and expressed a desire for it to be upscaled to the entire community. Perhaps the greatest economic challenge for the project was sustainable and sufficient funding, particularly for community engagement.

The remains of a small constructed wetland years after the project was implemented in the Langrug community, South Africa (Photo credit: Karen Esler).

The remains of one of the tree gardens (right) years after the project was implemented in the Langrug community, South Africa (Photo credit: Karen Esler).

The structure of the tree garden remains, but the tree itself is long gone. Some community members have repurposed the structures for other herbs and vegetables, while still others have been vandalised and the bricks stolen in Langrug, South Africa (Photo credit: Alanna Rebelo).

Gender dimensions

Implementation of the project was aimed at strengthening the community and therefore a diversity of people were involved, with attempts to have representation from females, males, youth and older people. A survey of community members revealed that the community felt that the Genius of SPACE project improved gender equality. This is largely related to the role women play in society, particularly around household tasks related to water, such as cooking and cleaning. Having access to waste-water disposal points saved travel time, and also improved household level sanitation. Employment opportunities were also created for women through this project.

Project team meeting of community members as part of the design phase of the Genius of SPACE project, Langrug, South Africa (Photo credit: Genius of SPACE Langrug Community Project).

Benefits

In terms of social impact, surveys among community members and workers involved in the Nature-based Solution revealed that people felt that: their connection to nature improved, that their cultural values and practices were changed, that their health and wellbeing improved, they experienced improved social cohesion and they reported improved gender equality. In terms of environmental benefits, the community perceived increases in the following ecosystem services: food provision, water purification, water regulation, soil quality maintenance, soil retention and recreation, aesthetic, science and education services. Lastly, in terms of economic benefits, job creation and income improvements were cited by community members and implementers, and the opportunity for indirect job creation, through tourism for example.

The informal community of Langrug with an improved road surface with permeable paving for stormwater management (left), and a functional greywater disposal point (blue plastic structure), Langrug (Photo credit: Alanna Rebelo).

Conclusion

Although the project idea was received very positively by community members, with many requesting a similar initiative in the future, the pilot project was deemed unsuccessful and was discontinued. Several barriers were too large to be overcome at the time. However there also exist several opportunities for future implementation of similar Nature-based Solutions. Challenges listed by implementers and community members were: social imbalances, rapid urbanization, crime and vandalism, poor communication and collaboration underpinned by weak relationships and lack of trust, which resulted in poor stakeholder support, and finally, lack of funding (sustainable and sufficient). Despite these challenges, there is still great appetite in the community for future nature-based solutions, as the benefits were tangible for community members. One of the key learnings is that future similar projects should apportion a significant amount of their budget (around 80%) for community and stakeholder engagement, as this appears more important than physical implementation for project success.

3.3.2 Dwars River Alien Tree Clearing Photo Story

Invasive alien tree clearing as a Nature-based Solution: The case of the Wildlands Trust, Dwars River, South Africa

A drone image of the Dwars River valley, in the Western Cape of South Africa, showing the rugged Boland Mountains in the background, and the arable valley in the foreground, supporting small towns, industry and agriculture (Photo credit: Cape Winelands Biosphere Reserve)

Introduction

The Nature-based Solution implemented by Wildlands Trust in the Dwars River riparian zone involves three approaches: (1) the clearing of invasive alien trees, shrubs and weeds from the riparian zone (initially through logging operations, with follow-up clearing), (2) active rehabilitation of the riparian zone, through the planting of indigenous tree seedlings, and (3) engaging the community through creating employment opportunities in the rehabilitation programme, as well as a recycling and native tree growing programme, aimed to keep the river clean, in exchange for rewards (e.g. bicycles). This project takes a social-ecological systems approach to restoration of a modified ecosystem to make services available to society, making it a key type of Nature-based Solution.

This Nature-based Solution specifically tackles the issue of water quantity, by trying to make more water available in the system through clearing water-guzzling invasive alien trees. In making more water available, it also addresses the secondary but equally important challenge of water quality, through dilution effects (making more water available to dilute contaminants). The scale of this implementation is still quite small, so benefits are expected to be local. Many community members

perceive improvements to nature (improvements in ecosystem services), which are experienced directly in terms of recreational benefits, improvements to aesthetics, and general well-being, social cohesion and nature-connectedness. Any benefits in terms of augmented water supply or quality, though perhaps small due to the scale of the work, would be beneficial to downstream farmers who rely on the Dwars and/or downstream Berg River for irrigation. The aim of this photo story is to highlight the value of invasive alien tree clearing as a nature-based solution through a series of photos, demonstrating both the implementation, but also the benefits to society.

The ecological, social, economic and political context

The Dwars River Valley is a small subsidiary catchment of the greater Berg River Catchment, one of the most economically important rivers for the Western Cape of South Africa. This small catchment has its origin in the Boland Mountains, which receive some of the highest rainfall of the country (~1600-3000 mm/a). The climate of the region is Mediterranean. The native vegetation is fire-prone fynbos, a biodiverse shrubland lacking a tree component, with the exception of the riparian zones along the river, which would have been forested. The catchment has become invaded by invasive alien trees, along the river as well as in the rest of the catchment.

The native vegetation of the Banhoek River Valley is fynbos, and the watershed of the catchment – the high Boland Mountains – are seen in the background. Alien trees have invaded this catchment (a sparse scattering seen here in the foreground), negatively impacting water supplies, increasing fire-risk, decreasing agricultural productivity and negatively impacting biodiversity (Photo credit: Cape Winelands Biosphere Reserve).

With its roots in the colonisation of the Cape, the Dwars River Valley and has ties to slavery and oppression. As a result, the current socio-economic context is highly complex, with large inequalities between wealthy landowners (in some cases lucrative agriculture and luxury properties) and people residing in the local towns. The communities are affected by high crime levels and drug abuse. The valley may be classified as peri-urban given the fast paced, and highly contested, spatial transformation currently taking place. In terms of population in the local towns, in 2011 there were around 1 975 people living in Pniel, 4 328 in Kylemore, and 4 289 in Lanquedoc. Much of the working population in the small towns are employed in seasonal labour, working on surrounding farms. The local government of the valley is rather weak and fragmented, and national government provides funds for this Nature-based Solution, but otherwise provides little support. This leaves implementation of this project up to local stakeholders, with championing of this work being key to success.

The social-ecological context of the Dwars River Valley. Wealthy landowners of farms intersperse the low-income towns of Pniel and Lanquedoc in the Dwars River Valley, South Africa, with stark inequalities compared to adjacent landowners.

Technical details of the Nature-based Solution

The social-ecological restoration involves three approaches and takes place either on municipal or privately owned land. Firstly, the clearing of invasive alien trees, shrubs and weeds from the riparian zone. The trees are cleared initially through logging operations, whereas subsequent follow-up clearing may involve foliar spray of herbicides, cutting and spraying of herbicides or hand-pulling, depending on the target invasive alien species. Secondly, there is active rehabilitation of the riparian zone, through the planting of indigenous tree seedlings. Thirdly, there is an attempt to engage the community through creating employment opportunities in the rehabilitation programme, as well as a recycling programme, aimed at keeping the river clean, and Treepreneurs Project. The Treepreneurs Project encourages and empowers school learners to grow trees and sell the seedlings to the project seven to eight months later for a reward (e.g. a bicycle).

First the riparian zone is cleared of invasive alien trees by heavy machinery. This part of the implementation is done by contractors. Care is taken to minimize damage to the riparian zone, but it is a high impact intervention. This photo is from lower down in the Berg Catchment, South Africa (Photo credit: Landcare).

Second the riparian zone is cleared of the debris by teams of 10-12 people with a site manager. Some people use chainsaws, while others clear the vegetation by hand, removing it from the riparian zone. This photo is from lower down in the Berg Catchment, South Africa (Photo credit: Landcare).

Third, teams do revegetation of indigenous species that would not be able to return by spontaneous recovery. Here a team is doing rehabilitation planting in the riparian zone of the Berg River, South Africa (Photo credit: Landcare).

Implementation of the Nature-based Solution

In terms of the actors involved in implementing this particular Nature-based Solution, the alien clearing work is coordinated by non-governmental organizations, in this case the Wildlands Trust, and falls under the banner of the South African national 'Working for Water' programme. There is some regional government interest in the rehabilitation work along the Dwars River, primarily that of the Department of Environmental and Development Planning (Western Cape Government). In terms of local governance, the Stellenbosch Municipality is involved, mainly through their role in wastewater treatment and maintenance of local parks close to the river. National government provides the bulk of the funding. There is some cross-pollination between tiers of government, for example the Department of Environment Affairs, Forestry and Fisheries (national government) specify catchment-based units of importance, and interventions are to be based on these specifications. However institutional fragmentation remains a major issue. National funding is in tandem with provincial planning, especially in the Natural Resource Management Programme; previously Working for Water, and all its affiliate groupings Working for Wetlands, Forests, etc.

An alien clearing team working clearing invasive alien trees in the Dwars River Catchment, South Africa (Photo credit: Lydia van Rooyen).

Challenges

Challenges faced in the process of implementation according to implementers were: institutional fragmentation, insufficient and unreliable funding, the absence of a platform to engage landowners, tension between implementers and community, or implementers and workers, unwilling landowners or stakeholders and illegal activities. Illegal actives hampered the process of implementation because alien trees often obscure crime (e.g. illegal water abstraction from the river) and this makes complicit stakeholders unwilling to participate in, or support, alien tree clearing. The importance of a champion to drive implementation has been noted, as well as the need for better and timely community engagement and communication, particular upfront. Secondary invasion and re-invasion is also an issue after alien tree clearing, if revegetation or active restoration does not take place.

Potentially illegal offtake from a weir on the Dwars River. Alien trees obscure such illegal activities in the Dwars River, South Africa. Alien trees remain in the river in the foreground (alien Oaks) and the watershed in the background (Photo credit: Alanna Rebelo).

Gender dimensions

The Working for Water programme in South Africa is funded by national treasury, and aims to create jobs, particularly for unskilled workers. It has very strict targets for this employment, including that a certain percentage should be female (60%), youth (20%) and disabled people (5%). The benefits of supporting women in finding employment are that there are more direct impacts on family security, for example the number of children being enrolled in schools. This has, however, also been shown to be impacted by the security of this employment, which is often tenuous in these programmes.

A female team member clears alien vegetation from the riparian zone of the Dwars River, South Africa (Photo credit: Lydia van Rooyen).

Benefits

In terms of social impact, surveys among community members and workers involved in the Nature-based Solution revealed that people felt that: their connection to nature improved, that their cultural values and practices were changed, that their health and wellbeing improved, they experienced improved social cohesion and they reported reduced crime. In terms of environmental benefits, the community perceived increases in the following ecosystem services: water provision, materials and energy provision, water purification, water regulation, soil quality maintenance, life cycle maintenance, and recreation, ornamental, aesthetic and heritage services. Lastly, in terms of economic benefits, job creation and income improvements were cited by community members and implementers, and lower fire risk to landowners was highlighted.

Before (left) and after (right) alien tree clearing, showing the riparian habitat becoming more open along the Dwars River near Kylemore, South Africa, with increased visibility and recreational opportunities. It will take time before the native vegetation recovers and for the site to become more aesthetically pleasing (Photo credit: Lydia van Rooyen).

Conclusion

Many lessons have been learnt through implementation of alien tree clearing as a Nature-based Solution in the Dwars River Valley context, and challenges and opportunities alike were identified. Challenges listed were: institutional fragmentation (especially within government), sustainable and sufficient funding (also earmarked funding for stakeholder engagement), long-term recovery versus society's desire for rapid change, implementing within the context of socially vulnerable communities, and where the value of the river not recognized by the community. Despite these challenges, several opportunities were also identified. Multi-level collaboration and engagement in terms of relationship with landowners, stakeholders, implementers and government was identified as a potential opportunity, as well as the chance to investigate and build a more flexible funding model for alien tree clearing (exploring options within the private sector), and the opportunity to couple alien clearing (rehabilitation) with active restoration at scale. This is likely to result in far greater returns on investment, due to native vegetation re-establishing and keeping secondary invasion and reinvasion by alien trees at bay.

4. Conclusion

We have found that nature-based solutions for water management in the peri-urban yield valuable ecosystem services to society, as well as additional livelihood, social and economic benefits. However the upscaling of these nature-based solutions is faced by several key barriers, and various enablers have been suggested to unlock this potential. These enablers suggest a socio-political context that would favour the implementation of nature-based solutions in the peri-urban at scale.

Challenges for implementing nature-based solutions

The main challenges for implementing nature-based solutions globally according to a workshop with the international project team are suboptimal planning processes and sustainable funding. Lack of strategy, legal/policy context, rapid urbanisation and silo mentality (fragmentation) also emerged as important.

From the international literature review, inadequate financial resources, institutional fragmentation and path dependencies and inadequate regulations/policies or the enforcement thereof emerged as important. Additionally, a key barrier for nature-based solutions in the peri-urban was rapid urbanisation and development.

From the South African Genius of SPACE case study, key challenges during the implementation included complex social and institutional issues including unsustainable funding mechanisms, social vulnerabilities, and lack of stakeholder support. For the Dwars River case study, stakeholder interviews revealed that despite the clear need for restoration, several barriers exist to successful implementation and that these stem from inadequate financial resources, inappropriate funding models, institutional challenges, and a lack of techno-scientific knowledge.

Lack of money for nature-based solutions to be applied at scale seems to be a common thread from all these studies. Despite this, there seems to be continuous funding for development of these peri-urban spaces at scale. This perhaps speaks to the need for creative financing models enforced through policy that would seek for development projects to incorporate nature-based solutions into their design.

The socio-political context that favours the implementation of nature-based solutions

The top enabler that emerged from the global review of nature-based solutions in the peri-urban was stakeholder engagement and collaboration. This is a key feature that emerged in our South African case studies as well, and investment into community engagement was highlighted by implementers as critical. A supportive policy context (i.e. plans, acts and legislations and the enforcement therefore) was found to be an important enabler in peri-urban areas.

Contributions to key research gaps

This study addressed a critical gap in the nature-based solution knowledge system, both in terms of focussing on the understudied peri-urban setting, but also in considering the Global South through a case study of grey literature in South Africa related to nature-based solutions for water management and two case studies. We found that including the Global South perspective has widened the narrative and yielded important insights which advances the growing field of nature-based solutions. In summary, we have found that nature-based solutions for water management in the peri-urban yield valuable ecosystem services to society, as well as additional livelihood, social and economic benefits.

5. Recommendations

We propose some recommendations for future research on nature-based solutions:

- More holistic measurement of the benefits of nature-based solutions (e.g. ecosystem services as well as social, livelihood and economic benefits) is needed for water management in the peri-urban (as opposed to focussing on one or two benefits in detail).
- More empirical research is needed on the ecosystem services and other benefits of agroforestry/urban forestry, agroecosystems/urban agriculture, combination and ecosystem protection as nature-based solutions to water management in the peri-urban (as opposed to only theoretical/conceptual studies).
- In general monitoring of nature-based solutions was found to be poor, as was field validation of modelling results. We recommend more field-based empirical research to quantify the benefits of nature-based solutions in the peri-urban and in other settings.

We propose some recommendations for implementers and decision-makers around nature-based solutions:

- New planning mechanisms are needed that are more flexible and respond to the complexities of peri-urban areas, steering development towards sustainability.
- We recommend that implementers budget for a significant investment into community engagement, especially in communities that are socially vulnerable.
- We recommend that implementers budget for a significant investment into long-term monitoring.
- We recommend the development of new, creative funding models to finance nature-based solutions.
- We recommend more investment into nature-based solutions to solve water management issues in peri-urban areas, given the demonstrated benefits to society.
- We recommend a creative and supportive policy framework to support the integration of nature-based solutions into peri-urban developments.

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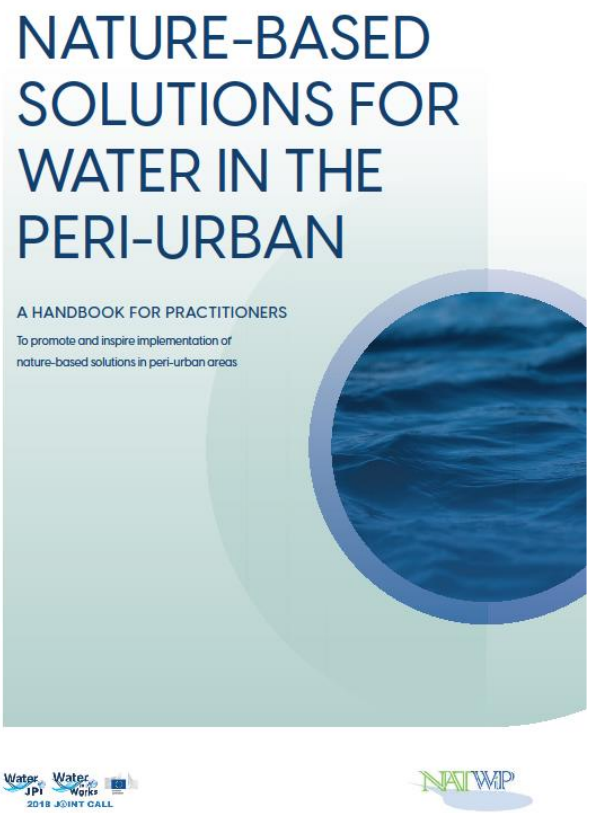
List of Appendices

Appendix 1: The NATWIP Handbook



Available on the WRC website: https://wrcwebsite.azurewebsites.net/wp-content/uploads/mdocs/Nature%20based%20solutions%20for%20water1.pdf

Appendix 2a: Implementer Interview Schedule

Interviewer Details

Questionnaire No.: _____

Interviewer Name: _____

Section 1. Context

Site Details

NBS Project:

Genius of SPACE □

Dwars River Rehabilitation □

Town: _____

Person Interviewed Details

Name: _____

Organisation: _____

Sector:

Local or regional government (GOV) □

Civil society incl NGO (CIV) □

Research, academia (UNI) □

Private sector/industry/business (IND) □

Citizens (communities/end-users / individuals) (CIT) □

Other Water and/or NBS-related actors (OTH) □

Contact Number: _____

e-mail: _____

What was your role in the NBS? _____

_____

Dimension 1: Social

The Community

Before the implementation of the NBS project, what challenges and pressures were present in terms of water-related social issues (drug trafficking, real estate speculation, society's involvement in problems/ Preserve spaces related to the water cycle/ Awareness of the value of nature/ other), if any? _____

_____

Before the NBS project, how would you describe the health and well-being of the community?

_____

Before the NBS project, how would you describe the access the community had to water?

_____

Would you say that both women and men had equal access to water?

Yes □ No □, If no, please describe: _____

Before the NBS project, how would you describe how the community used nature? Was it used for recreation, or any cultural or spiritual practices? _____

_____

The NBS

Are there supporting policies for embarking on NBS? (if yes, please describe)_____

_____

How coherent and helpful are these policies? _____

_____

Dimension 2: Economic

Before the NBS how would you describe the economic status of the community? (joblessness, property values, household income) _____

_____

Dimension 3: Environmental

What challenges and pressures were the system facing in terms of water quantity (Floods/Drought/Water supply/Climate change), if any, before the NBS was implemented? _____
_____
_____

What challenges and pressures were the system facing in terms of water quality (Pollution/eutrophication/impact on human health via ingestion), if any, before the NBS was implemented? _____

_____

What is the type of NBS you are implementing? _____

What other NBS projects (if any) are in place in the area? _____

At what scale were you aiming to implement?

Local (Site/Neighbourhood/Municipality) □

Regional (Basin level) □

National □

Other □

Did you aim to address any of the SDG's with this NBS? If yes, please list them. _____

_____

How many different types of actors are involved in this NBS that you are aware of?

Local or regional government (GOV) □

Civil society incl NGO (CIV) □

Research, academia (UNI) □

Private sector/industry/business (IND) □

Citizens (communities/end-users / individuals) (CIT) □

Other Water and/or NBS-related actors (OTH) □

Section 2. Process

Dimension 1: Social

What was the location(s) of the interventions? Were they typically on private property or community-level property?

Private property □ Community-level property □

How did you experience the project management throughout all stages (planning, pilot, construction, process, monitoring)? _____

_____

Was there sufficient expertise, skills and knowledge of all the involved actors?

Yes □ No □, If no, what was the issue? _____

_____

Were there any specific personal values and attributes that facilitated the NBS process?

Yes □ No □, If yes, please list these, and who possessed them:

_____

_____

Was the NBS interdisciplinary? (i.e. did you feel that the right expertise was present, no silo's?)

Yes □ No □, If no, why not? _____

_____

Did you feel that there was sufficient and relevant collaboration in this NBS project?

Yes □ No □, If no, why not? _____

_____

Did you experience any power struggles between actors during implementation?

Yes □ No □, If yes, please describe: _____

_____

Did you witness any power struggles within the community?

Yes □ No □, If yes, please describe: _____

_____

Would you say this NBS was a bottom-up or top-down initiated and driven process?

Bottom-up □ Top-down □, Any qualifying comment you would like to make?

_____

Was there sufficient political support?

Yes □ No □, If no, please explain why not? _____

_____

Were societal/cultural values incorporated into the NBS implementation?

Yes □ No □

If yes, what activities were arranged to do this?

_____

_____

Was there any conflict or tension among actors during implementation?

Yes □ No □, If yes, please explain why? _____

_____

Would you say there was joint ownership of the NBS?

Yes □ No □, If no, please explain why not? _____

_____

Dimension 2: Economic

What was the funding situation? _____

_____

Would you describe the funding as sustainable and long-term or not?

Sustainable, long-term □ Unsustainable, Short-term □

Who was the main funder? _____

Is the main funder public or private?

Public Investor □ Private Investor □

Was there any co-funding from other sources?

Yes □ No □, If yes, who: _____

What kinds of costs are supported?

Personnel □ Maintenance □

Participatory processes □ Communication □

Other □ (please describe) _____

Did you try to encourage private investment?

Yes □ No □, If yes, what business model was used to attract it?

_____

Dimension 3: Environmental

What was the total area of trees cleared? _____

What was the total area of active rehabilitation? _____

How many plants were planted? _____

How many greywater water disposal points were constructed? _____

How many vertical wetlands were constructed? _____

How many tree gardens (water filtering sites) were constructed? _____

What was the area of stormwater management constructed? (improved road surface with permeable paving) _____

For the collection and separation of household solid waste in wheelie bins (compostables, recyclables, non-recyclables), how many bins were bought/delivered? _____

How many water harvesting structures were constructed? _____

Were any other interventions implemented that are not recorded here? _____

Dimension 4: Technical

Did you experience any technical challenges, such as biophysical knowledge gaps, lack of technical expertise, lack of space etc?

Yes □ No □, If yes, please describe these: _____

_____

Was there any capacity building that happened because of the NBS implementation?

Yes □ No □, If yes, please describe this (was this in the communities, or the actors themselves?): _____

_____

Section 3. Results

Dimension 1: Social

Are you aware of any instances of the NBS affecting the environmental identity of the community?

Yes □ No □, If yes, please describe these: _____

_____

Are you aware of any instances of the NBS shaping the way the community uses nature for recreation?

Yes □ No □, If yes, please describe these: _____

_____

Are you aware of any instances of the NBS shaping the cultural values and practices of the community?

Yes □ No □, If yes, please describe these: _____

_____

Has the NBS improved the health and wellbeing of the community in any way?

Yes □ No □, If yes, please describe these: _____

_____

Did access of water for daily use improve for the community after the NBS?

Yes □ No □, If yes, please describe these: _____

_____

Did water become more available for alternative uses for the community after the NBS?

Yes □ No □, If yes, please describe these: _____

_____

Did gender equality of the community improve when it came to accessing water, after the NBS?

Yes □ No □, If yes, please describe this: _____

_____

Did any policies on NBS come out following the NBS?

Yes □ No □, If yes, please describe these: _____

_____

Was lack of legislation around the NBS an issue?

Yes □ No □, If yes, please explain: _____

_____

Was there good participation from the community?

Yes □ No □, If no, please explain the issues: _____

_____

Dimension 2: Economic

Are you aware of the NBS creating new jobs in the community?

Yes □ No □, If yes, please describe how: _____

_____

Are you aware of any improvement in household income?

Yes □ No □, If yes, please describe what: _____

_____

Are you aware of any jobs indirectly created (e.g. through tourism?) due to the NBS?

Yes □ No □, If yes, please describe these: _____

_____

Are you aware of any improvement in property value following the NBS?

Yes □ No □, If yes, please explain: _____

_____

Were there any other economic benefits of the NBS, such as avoided costs? (e.g. for water treatment, water supply, irrigation, reduced fire risk etc)

Yes □ No □, If yes, please describe these: _____

_____

Dimension 3: Environmental

Did any of these ecosystem services improve, decline or stay the same after the NBS in your opinion:

		Ecosystem Service	Examples	Improve (√) / Decline (x)/ Same (-) / Unsure (?)
Provisioning	1	Food Production	Fruit, vegetables, livestock	
	2	Water Provision	Access to water	
	3	Materials & Fibre	Wood	
	4	Energy & Fuel	Firewood	
	5	Genetic Resources	-	
	6	Medicinal Resources	-	
	7	Ornamental Resources	Flowers	
Regulating	8	Water Purification	Clean water	
	9	Water Regulation	Less droughts, less floods	
	10	Air Quality Regulation	Cleaner air	
	11	Soil Quality Regulation	Healthy soils	
	12	Soil Retention	No erosion	
	13	Climate Regulation	Carbon trapped	
	14	Pollination	Bees	

	15	Life Cycle Maintenance	-
	16	Biological Control	Pest control
Cultural	17	Recreation & Tourism	Enjoying/using nature
	18	Scientific & Educational Services	Using nature for learning
	19	Heritage, Cultural, Bequest, Inspiration & Art	Using nature for inspiration
	20	Aesthetic Services	Find nature beautiful
	21	Symbolic, Sacred, Spiritual & Religious Services	Use nature for practices

Section 4. Concluding Remarks

Can you rank your top three most important challenges for implementing this particular NBS?

Silo mentality	□	Lack of strategy	□
Sustainable funding	□	Sufficient funding	□
Priorities not aligned	□	Technology complicated	□
Real estate speculation	□	Violence/Crime	□
Stakeholder support	□	Uncertainty	□
Sensitivity of area	□	Multilevel coordination	□
Lack of technical expertise	□	Suboptimal planning process	□
Champions	□	Political will	□
Legal/policy context	□	Town planning (ignorance)	□
Collaboration (govt & society)	□	Rapid urbanisation	□
Social imbalance	□	Socially vulnerable communities	□

Are there any comments you would like to make in conclusion, or any issues you think are important that we have not covered?

Thank you for your time!

Appendix 2b: Community Interview Schedule

Interviewer Details

Questionnaire No.: _____

Interviewer Name: _____

Section 1. Context

Site Details

NBS Project:

Genius of SPACE □

Dwars River Rehabilitation □

Town: _____

Person Interviewed Details

Name: _____

Contact Number: _____

Province of Origin: _____

Dimension 1: Social

How many years have you been living here? (Mark relevant box with an x)

0 - 2 years	□	11 - 20 years	□
3 - 10 years	□	20+ years	□

What type of home do you live in?

Main house □

Backyard dwelling □

What is your building structure?

Brick and mortar □

Wood □

Zinc □

Other □ Specify: _____

How many people are in your household? _____

Is your household head male or female? _____

Age of household head: _____

How many children are in your household? _____

What are the major issues in your community? (e.g. could be crime, health, income, water etc)

Dimension 2: Economic

How many people in your household have a job? _____

What is the nature of your employment?

Full Time	□
Part Time	□
Permanent	□
Contract	□
Seasonal (having employment for a seasonal period)	□
Casual (having employment on an ad hoc basis)	□

Does your household receive any of these municipal services? (Mark relevant answers with an x)

Electricity	□	Refuse removal	□
Water	□	Sewerage	□

Dimension 3: Environmental

[Explanation text (to be developed to be specific for each NBS): A few years ago, an NBS was applied in your community. Could you help us to think back to before this project started, and describe your situation at that time?]

Did you experience any issues around water quantity (Floods/Drought/Water supply/Climate change), before the NBS? If yes, please describe: _____

_____

Did you experience any issues around water quality (Pollution/eutrophication/impact on human health via ingestion), before the NBS? If yes, please describe: _____
_____

Did you experience any other issues around water (drug trafficking, lack of env awareness), before the NBS? If yes, please describe: _____
_____

Before the NBS project, did you use nature for recreation, or any cultural or spiritual practices? If yes, please describe: _____
_____

Before the NBS, how would you describe your health and well-being? : _____
_____

Before the NBS, how would you describe your access to water? : _____
_____

Before the NBS, what was your household's main source of drinking water? (Mark relevant answers with an x)

Piped (tap) water in house	□	Borehole water in yard	□
Piped (tap) water in yard	□	Borehole outside yard	□
Rain-water tank in yard	□	Public/communal tap	□
Neighbour's tap	□	Well point	□
Inside main house (if backyarder)	□		

Before the NBS, what did you use water for?

Washing clothes	□	Bathing/ washing	□
Cleaning the house	□	Home business use	□
Watering the garden	□	Watering livestock	□

Before the NBS, would you say that both women and men had equal access to water?

Yes □ No □, If no, please describe: _____

Section 2. Process

How well do you think the NBS was implemented? (e.g. trees cleared, trees planted, green infrastructure installed) _____

_____

Were you consulted? (part of the process?)

Yes □ No □

Are you aware of others in the community who were consulted?

Yes □ No □, If yes, please describe why they were included and you were not:
_____

Is there anything you would have recommended they do differently? _____

_____

Section 3. Results

Dimension 1: Social

Has the NBS shaped the way you view your environment, or your environmental identity?

Yes □ No □, If yes, please describe how:
_____

Has the NBS shaped the way you use nature for recreation?

Yes □ No □, If yes, please describe how:
_____

Has the NBS shaped your cultural values and practices at all?

Yes □ No □, If yes, please describe how:
_____

Has the NBS improved your health and wellbeing in any way?

Yes □ No □, If yes, please describe how:
_____

Did you find that your access of water for daily use improved after the NBS?

Yes □ No □, If yes, please describe how:

_____

Did water become more available for other uses?

Yes □ No □, If yes, please which uses you now use water for that you didn't before:

_____

Did you find improved gender equality when it came to accessing water, after the NBS?

Yes □ No □, If yes, please describe how:

_____

Did you find reduced crime following the NBS?

Yes □ No □, If yes, please describe how:

_____

Did you find improved social cohesion following the NBS?

Yes □ No □, If yes, please describe how:

_____

Dimension 2: Economic

Did the NBS create new jobs in your community?

Yes □ No □, If yes, please describe how:

_____

Did your own work situation change due to the NBS?

Yes □ No □, If yes, please describe how:

_____

Were you employed directly by the NBS?

Yes □ No □, If yes, please describe how:

_____

Did you get a job indirectly due to the NBS (e.g. tourism?)

Yes □ No □, If yes, please describe how:

_____

Was there an improvement in property value following the NBS?

Yes □ No □, If yes, please describe how much:

_____

If your employment situation changed, was there an improvement in household income?

Yes □ No □

Dimension 3: Environmental

Did any of these ecosystem services improve, decline or stay the same after the NBS in your opinion:

		Ecosystem Service	Examples	Improve (√) / Decline (x)/ Same (-) / Unsure (?)
Provisioning	1	Food Production	Fruit, vegetables, livestock	
	2	Water Provision	Access to water	
	3	Materials & Fibre	Wood	
	4	Energy & Fuel	Firewood	
	5	Genetic Resources	-	
	6	Medicinal Resources	-	
	7	Ornamental Resources	Flowers	
Regulating	8	Water Purification	Clean water	
	9	Water Regulation	Less droughts, less floods	
	10	Air Quality Regulation	Cleaner air	
	11	Soil Quality Regulation	Healthy soils	
	12	Soil Retention	No erosion	
	13	Climate Regulation	Carbon trapped	
	14	Pollination	Bees	
	15	Life Cycle Maintenance	-	
	16	Biological Control	Pest control	
Cu	17	Recreation & Tourism	Enjoying/using nature	

l	1	Scientific & Educational Services	Using nature for learning
t	8		
u	1	Heritage, Cultural, Bequest, Inspiration & Art	Using nature for
r	9		inspiration
a	2	Aesthetic Services	Find nature beautiful
l	0		
	2	Symbolic, Sacred, Spiritual & Religious	Use nature for practices
	1	Services	

Section 4. Concluding Remarks

Are there any comments you would like to make in conclusion, or any issues you think are important that we have not covered?

Thank you for your time!

Appendix 3a: The NATWiP Framework Template

The NATWiP Framework template can be downloaded as an Excel file; you can then apply it to your own nature-based solutions case study.

MAY YOU HAVE EVERY SUCCESS IN PURSUING NATURE-BASED SOLUTIONS THAT ARE SUSTAINABLE.

	INFORMATION RECQUIRED	SPECIFICATION	EXAMPLES
SETTLEMENT	LOCATION	Continent	
		Country	
		City	
	TYPE		Urban, peri-urban, rural...
	THREATS		Lack of legislation, absence from the state...
	OPPORTUNITIES		Labor, participatory community ...
PROBLEM AND SCALE	CHALLENGE		Floods/Drought/Water suply/Climate changes/ Society's involvement in problems/ Preserve spaces related to the water cycle/ Awareness of the value of nature/ other
	PRESSURE	LOCAL SCALE	Drug trafficking, real estate speculation, water pollution ...
		LANDSCAPE SCALE	
	ACTORS INDENTIFICATION		List of institutions in the area related to the target (local or regional government/ Civil society/ Academia/ Industry/ Other)
TARGET	SDGs ASSOCIATION		Goals number
	OTHER PROJECT IN PLACE		

Appendix 3b: South African indicator spreadsheet

This is the completed NATWiP Framework for the two South African nature-based solutions. You can find an overview of: 1) the types of indicators that may be used for each of the three project phases (context, process and results); 2) the types of indicators used for all three dimensions of sustainability (economic, social, environmental); and 3) an illustration of how results may be captured through semi-structured surveys.

Key

Perceptions	Different questions were directed to community members VS implementers
Empirical	Data taken from reports/literature
Questions/Comments	

South African case studies included in this spreadsheet

Genius of SPACE
Dwars River Rehabilitation

Sample Sizes

Genius of SPACE	community members: n=23; implementers: n=8
Dwars River Rehabilitation	community members: n=20; implementers: n=3

Context

						Genius of Space (community members: n=23; implementers: n=8)		Dwars Rehabilitation (community members: n=20; implementers: n=3)	
	INFORMATION REQUIRED	**SPECIFICATION**	**SCALE (for challange**	**EXAMPLES**	**Definition/ notes/expl**	**INDICATOR**	**SCALE**	**INDICATOR**	**SCALE**
SETTLEMENT	LOCATION	Continent				Africa		Africa	
		Country				South Africa		South Africa	
		City				Langrug		Pniel	
	TYPE			Urban, peri-urban, rural...		Peri-Urban		Peri-Urban	
NBS	TYPE	Restoration, river park, biowasle, green roof...				Green infrastructure		Riparian rehabilitation	
	SCALE	Local - Site/Neighbourhood/Municipality, Regional - Basin level, National and Other				Local: Site		Local: Site/Neighborhood (this is river/riparian rehabilitation, so it is in strips along the river within a subcatchment)	
	AVAILABILITY AND SUPPORTING POLICY COHERENCE	Are there supporting policies for embarking on NBS and to which extent these and other policies related directly or indirectly to water are coherent in supporting NBS				No official policies but aimed that the project would contribute to policies related to NBS.		Yes, there is the NEMA Act. Supportive: penalties for non-compliers; but seldom enforced/implemented (Policing done by Green Scorpions and they are dysfunctional; the laws are open to interpretation)	
PROBLEM AND SCALE	CHALLENGE AND PRESSURES	WATER QUANTITY		Floods/Drought/Water suply/Climate changes	Indicate the scale of the challange and pressure as: Individual, Neighborhood/ Local, Watershed /Regional and National. For example, where individual drinking	**Community:** Floods (16), Droughts (14), Water Supply (13); **Implementers:** Floods (6), Drought (1), Water Supply (3), Climate Change (1)	Neighborhood	**Community:** Floods (7), Droughts (3) Water Supply (1), Other (3), Farmers are abstracting water from the river, sometimes illegally (2); **Implementers:** Floods (2), Droughts (2)	Neighborhood
		WATER QUALITY		Pollution/eutrophication/impact on human health via ingestion		**Community:** Pollution (19), Eutrophication (4), Disease (10); **Implementers:** Pollution (7), Eutrophication (5), Disease (6)	Neighborhood, Region	**Community:** Pollution (13), Eutrophication (9), Disease (0), Other (1), Municipal water tastes like chemicals, so uses spring/rain water (1); **Implementers:** Eutrophication (3), pollution (2), stormwater run-off, pesticides/herbicides from agricultural runoff, effluents from developments, sewage, too much Chlorine from water treatment	Neighborhood, Region
				Drug trafficking, real estate		Are there other water-related issues: **Community** (yes = 19); **Implementers** (yes = 8); **Community**: Theft of water-related infrastructure & sewerage (6), Lack of water-related infrastructure (above ground drains, distance, over-use) (5), Kids play in/waste water (4), Lack of sewerage (2), Resale on the black market (2), Community health hazard (kids playing in sewage) (1), Drug issues (1), Illegal solid waste disposal (1), Illegal	Neighborhood, Region	Are there other water-related issues: **Community** (yes = 10); Litter (3), Drug & alcohol abuse (2), Farmers extracting river water (illegally) (2), Lack of respect for the environment (2), Lack of environmental awareness (1), Vagrants (1), Violence (1), Robbery (1), Illegal Activities (1); **Implementers**: Crime, theft, illegal dumping in the river, inappropriate developments too close to the river, sewage flowing into the river, litter, poor service delivery in	Neighborhood, Region

PROBLEM AND SCALE	CHALLENGE AND PRESSURES	WATER RELATED SOCIO ECONOMIC ECOLOGICAL		Drug trafficking, real estate speculation, Society's involvement in problems/ Preserve spaces related to the water cycle/ Awareness of the value of nature/ other	/Regional and National. For example, where individual drinking water wells are the source, the challenge of quality is faced at individual scale but if there is piped water supply based on a heavily	Are there other water-related issues: **Community** (yes = 19); **Implementers** (yes = 8); **Community**: Theft of water-related infrastructure & sewerage (6), Lack of water-related infrastructure (above ground drains, distance, over-use) (5), Kids play in/waste water (4), Lack of sewerage (2), Resale on the black market (2), Community health hazard (kids playing in sewage) (1), Drug issues (1), Illegal solid waste disposal (1), Illegal use of water (1), Lack of water (1), People waste water (1), Theft & damage to water-related infrastructure (1), Vandalism of water-related infrastructure (1), Violent crime (1); **Implementers**: Lack of sewerage (sewage flowing above ground) (4), Downstream impacts of pollution (agriculture, prestigious wine-farms) (2), Greywater pollution in streets (distance to disposal points) (2), Health problems due to sewage (2), High E. coli count in river due to sewage (1), Lack of maintenance of sewerage (1), Lack of ownership of sewerage (1), Lack of service delivery (1), Lack of solid waste removal services (1), Municipality cannot provide sewerage (recent immigration) (1), Violent crime (dangerous walking to toilet at night) (1).	Neighborhood, Region	Are there other water-related issues: **Community** (yes = 10); Litter (3), Drug & alcohol abuse (2), Farmers extracting river water (illegally) (2), Lack of respect for the environment (2), Lack of environmental awareness (1), Vagrants (1), Violence (1), Robbery (1), Illegal Activities (1); **Implementers**: Crime, theft, illegal dumping in the river, inappropriate developments too close to the river, sewage flowing into the river, litter, poor service delivery in Lanquedoc, dangerous river crossings for Lanquedoc, drug abuse	Neighborhood, Region
	ACTORS INDENTIFICATION	Those involved in the NBS		List of actors cclassified as: Local or regional		**Implementers**: GOV, CIV, UNI, IND, Citizens, Other Water and/or NBS-related actors	Neighborhood, Region	GOV, CIV, UNI, IND, Citizens, Other Water and/or NBS-related actors	Neighborhood, Region
TARGET	SDGs ASSOCIATION			Goal and target	List the goals and	**Implementers**: Not initially explicitly considered; but the NBS ended up addressing SDG 1, 3, 6, 10, and 11.	Neighborhood, Region	Not initially explicitly considered; but the NBS ended up addressing SDG 6, 14, and 15.	Neighborhood, Region
	OTHER PROJECTS IN PLACE				List other types of initiatives	**Implementers:** The Water Hub (green infrastructure) (5); Alien Clearing Programmes (e.g. Wildlands) (2); Wetlands for water filtration (Stellenbosch, Isidima)	Neighborhood, Region	The Water Hub, other alien clearing initiatives (e.g. Simonsberg Conservancy), the Banhoek Conservancy, the Cape Winelands Biosphere Reserve.	Neighborhood, Region
		Cultural		Environmental identity	In order to allow a compariso n before and after	**Community**: (yes = 8); Kids use nature for recreation (5), Church (2), Resting (under a tree, in the sun) (2), Gardening (1), Singing at meetings, weddings, community events (1), Watching soccer matches (1)	Neighborhood	**Community:** (yes = 16), Relaxing (12), Swimming (9), Walking/Hiking (4), Pinicking/Braaiing (4), Camping (2), Drive-throughs (1), Wood harvesting (1)	Neighborhood
				Recreational values					
				Cultural values and practices					

SOCIO-ECONOMIC	SOCIAL	Health and well-being		Effects of water quality	the NBS we ask that you fill in any relevant information from the list here in the context tab as the "baseline" and then again after the intervention in the results tab. The cases which have been completed may have this information in the context and results tabs. The case studies that have	**Community:** Average health of community = 3.3 (scale of 1-5; 1=unhealthy; 5=very healthy); **Implementers:** Average health of community = 2 (scale of 1-5)	Neighborhood	**Community:** Average health of community = 3.85 (scale of 1-5; 1=unhealthy; 5=very healthy); **Implementers**: Average health of community = 2.83 (scale of 1-5)	Neighborhood
				Effects of water supply					
		Improving water related social values and services		Equitable water access for daily use		**Community:** Communal tap (21), Tap in house (1), Tap in yard (1); of those with communal taps, 1/3 say that the taps are not far, and 2/3 say that there is a significant access issue due to distance.	Neighborhood	**Community:** Tap in the House (13), Borehole (2); Good access to water (17), poor access to water (3)	Neighborhood
				Water availability for different		**Community:** Washing (17), Cleaning (13), Cooking (13), Drinking (5), Gardening (4)	Neighborhood	**Community:** Washing (14), Cleaning (11), Gardening (11), Bathing (13), Home Business (1), Livestock (3)	Neighborhood
				Gender equity		**Implementers:** there is gender equality (7), Women collect water more often (2); only women work with water; more physically challenging for women; women are worse off in terms of sanitation; **Community:** there is gender equality (11), women use more water (5).	Neighborhood	**Community:** there is gender equality (17), it was unsafe for women to use the river recreationally due to dense alien tree infestations (1); **Implementers**: there is equal access to water.	Neighborhood
		Social learning and institutionalisation		Policies related to NBS		How does this differ from first question about policies?			
	ECONOMIC	Income and Jobs		Income generating activities created directly/indirectly		**Implementers:** Joblessness (4.13), Property Value (0.88), Household Income (1.75) [on a scale of 1 to 5: 1 being very low, 5 being high]; **Community:** Have jobs (n=3); Type of job: Full Time (1), Seasonal (4), Contract (1), Casual (6). [these indicators are framed as results. We kept 'results' for the results tab, and only report on context here]	Neighborhood	**Implementers:** Joblessness =2, Property Value = 4, Household Income = 1.5, however there is high inequality (extremely poor to extremely wealthy), with fewer wealthy and many more that are poverty stricken; **Community:** Have jobs (n=17); Type of job: Contract (9), Full-time (4), Perm anent(2), Casual (1), Part-time (1), Seasonal (0). [these indicators are framed as results. We kept 'results' for the results tab, and only report on context here]	Neighborhood
				Jobs created directly/indirectly					
				Property value					
				Household income					
		Avoided Costs		Water treatment costs		N/A		N/A	
				Fertilizers costs		N/A		N/A	
				costs		N/A		N/A	
				Irrigation costs		N/A		N/A	

Process

	INFORMATION RECQUIRED		EXAMPLE	DEFINITION	Genius of Space (community members: n=23; implementers: n=8)	Dwars Rehabilitation (community members: n=20; implementers: n=3)
	DIMENSION	CATEGORY	INPUT/OUTPUT INDICATORS		INPUT/OUTPUT INDICATORS	INPUT/OUTPUT INDICATORS
	ENVIRONMENTAL	INTERVENTIONS	Number of tree seedlings planted		N/A	N/A
			Number of green roofs implemented		N/A	N/A
			Number of roads recovered		N/A	N/A
			Area that received the green and blue infrastructure		N/A	N/A
			Rate of plants planted survival		N/A	Unknown (we have data on diversity indices for
			Area of alien trees cleared		N/A	2km
			Area of active rehabilitation		N/A	235 ha
			Number of propagules planted		N/A	688
			Number of pipes installed		N/A	N/A
			Compliance with health & safety plans?		N/A	N/A
			Greywater water disposal points constructed		27	N/A
			Vertical wetlands constructed		1 was planned, but according to some, the wetland was never installed.	N/A
			Tree gardens (water filtering sites) constructed		15 were planned, but according to the implementer	N/A
			Stormwater management (improved road surface with permeable paving)		3m x 200m (Still establishing the exact total area)	N/A
			Collection and separation of household solid waste in wheelie bins (compostables, recyclables, non-recyclables)		20/42 Wheelie bins	N/A
			Fabrication of ecomachines		N/A	N/A
			Number of water harvesting structures created and/or restored (e.g. lake, pond, tank)		N/A	N/A
			Number and types of watershed structures created and/or restored (e.g. gabion, checkdam, water absorption		N/A	N/A
			Number and area of encroachment cleared from water harvesting structures and their network		N/A	N/A
			Number and types of nature-based wastewater treatment units installed and/or renovated		N/A	N/A
			Location of intervention - individual property or community-level (should this be in the "context" tab?)		50% state community level and 50% private (municipal) property	Private property and community property. The local government does not own the land but they are responsible for what happens in the streams.
			Wetlands		N/A	N/A
			Permeable paving		3m x 200m (Still establishing the exact total area)	N/A
			Water harvesting structures and their network		N/A	N/A
			Infiltration facilities		N/A	N/A
			Other		N/A	N/A
		PROJECT MANAGEMENT (throughout all stages:	Expertise, skills and knowledge of the involved actors		*How well do you think the project was run?* **Community:** 3.5 (1 = very poor; 5 = very good); **Implementers:** well run, it started very well but commitment fizzled out, failed to consider risks and how to mitigate them; failed to budget for 80% engagement, 20% work (in community work). Was there sufficient expertise, knowledge and skills of actors? **Implementers:** yes = 6 (no = 1: initially no, steep learning curve for all).	**Community:** Do you think the project was well run? Yes =14. *How did you experience the project management throughout all stages (planning, pilot, construction, process, monitoring)?;* **Implementers**: It was challenging, when you have various role players. To get everyone on the same page was difficult. You need to take the community through the journey and communicate with them.It was well managed (yes = 3). *Was there sufficient expertise, skills and knowledge of all the involved actors?* **Implementers**: yes = 3. The NBS team is well trained. One of the contracters lacked managerial skills.

		planning, pilot study, conceptual design, construction and monitoring)	Personal values and attributes that facilitate the NBS process	For example leadership, championship	One champion was mentioned by implementors. *Were there any specific personal values and attributes that facilitated the NBS process?* **Implementers:** yes = 6 (no = 1: engineers continued as normal). Specific examples: Needing to be engaging, empathy and support. Willingness to be involved in a bit of a fight - environmental and social justice to clean water and to be part of a process. There was a strong sense and commitment and principle based on a co-create, co-design approach. A lot of investment in their participation and understanding and ultimately their involvement. Definitely a level of resilience and commitment. Ability to speak to and negotiate with people who are directly affected by it and built trusts which led to newly acquired values.	There is one champion who obtains the funding and manages the project. *Were there any specific personal values and attributes that facilitated the NBS process?* **Implementers**: yes = 3; the champion lives in the valley, as do the workers (everyone is local).
		GOVERNANCE	Roles and responsbilities of involved actors	List all of the actors involved and provide their responsibilities	This project was a collaborative effort between GOV, CIV, IND and Citizens, with UNI playing a research role.	CIV: is the main actor (Wildlands Trust); GOV (national) provides funding, and UNI support with research.
			Power	For example personal power, positional power, societal groups power	*Was the project interdisciplinary?* **Implementers:** yes = 7. Project was very interdisciplinary and there was a lot of collaboration, especially between the implementers and community members. Although, collaboration was often lacking regarding the municipality. Only one implementer felt that this was not the case (was a bit of silo's, not enough public participation meetings. Would have worked a lot better if e.g. surrounding farmers were involved). Power struggles were present in the community but not significant. Certain individuals with agendas or trying to reach a leadership position.	*Was the project interdisciplinary?* **Implementers**: yes = 3. Project was very interdisciplinary, champion involved everyone who had valuable research input; *Were there power struggles?* **Community:** power struggles are present (3); issues around housing, implementers not considering local input, lack of community engagement.
	SOCIAL GOVERNANCE		Societal groups' role in the NBS at the different phases of planning cycle and whether it is top down or bottom up		**Community:** 13 people *said they were approached to be involved* . Initially the project was initiated via a top-down approach, but eventually became bottom-up driven. The goal was always for it to be bottom-up. *Was there sufficient collaboration?* **Implementers**: yes = 5; the three that said no indicated that municipality could have been more involved, and also local farmers. *Top-down or bottom-up?* **Implementers**: both = 6, top-down = 2. Initiated top-down but bottom-up i.t.o co-creation process (and became more bottom-up with time)	**Community:** 13 were consulted about the project. **Community**: 11 were directly involved in the project (9 people said it was easy to get involved in the project). *Was there sufficient collaboration?* **Implementers**: yes = 3; both positive and negative collaborative experiences, but overall good. *Top-down or bottom-up?* **Implementers**: both = 2; it started with Wildlands (top-down) and once the community members (boards and trusts) got involved they also contributed

	INFORMATION RECQUIRED		EXAMPLE	DEFINITION	Genius of Space (community members: n=23; implementers: n=8)	Dwars Rehabilitation (community members: n=20; implementers: n=3)
PROCESS (CASE)		POLITICAL SUPPORT	Political support and commitment for driving, planning and implementation of the NBS		*Was there sufficient political support?* **Implementers:** yes = 6. A challenge for implementation was weak support from local government (municipal level).	*Was there sufficient political support?* **Implementers**: yes = 2 (national government and municipality). A challenge for implementation was weak support from local government (municipal level).
			Political support and commitment after implementation of the NBS –in maintenance, monitoring, evaluation phases		This was a pilot project. Since it failed, the actors pulled out at the end of the implementation phase. There was sufficient political support at the beginning of the project.	A challenge for implementation was weak support from local government (municipal level). At a national level (funding), government is unreliable with payments (security and sustainability of funding), presenting challenges to implementation.
		CULTURAL/ AWARENESS OR EDUCATIONAL	Identified societal/cultural values that are incorporated in the planning and designing of NBS		*Were cultural/societal values sufficiently incorporated?* **Implementers**: yes = 6. Cultural/societal values were mainly incorporated via the planting elements and placement of infrastructure. Indigenous plants were selected.	Alien tree clearing protects cultural heritage (indigenous fynbos and ecosystems). *Were cultural/societal values sufficiently incorporated?* **Implementers**: yes = 3. Treeprenuers Project: school learners grow trees and sell the seedlings to the project 7 or 8 months later for a reward (e.g. a bicycle). Environmental outreach days were held at schools (with tree-planting initiatives). The project informed the community, and asked for input and how to involve the community.
			Activities/ campaigns that are launched to support the socio-cultural approach/values within NBS		Many workshops and meetings with the community were held.	N/A
			Identified local knowledge that is incorporated in the planning and designing of NBS		Local knowledge and cultural/societal values were mainly incorporated via the planting elements and placement of infrastructure.	N/A
			Identified awareness and educational programs for system users and relevant societal groups that are associated with the planning cycle processes of the NBS		Many workshops and meetings with the community were held.	N/A
		WORKING CULTURE	Conflictual/tension/collaborative interaction among actors invloved		*Conflict/tension among actors?* **Implementers:** yes = 4. Quite a bit of tension with the community at times i.t.o work ethics, contracting, payment. Also level of theft, vandalism and loss of materials. Limited buy-in from municipality (their property) and break down in communication at times which led to difficult situations when it came to implementing. *Power struggles among actors?* **Implementers:** yes = 3 (political and within the community). *Power struggles in the community?* **Implementers:** yes = 4. In a healthy, dynamic way; some key members of the community trying to ensure that they were seen as the legitimate leadership; ego's, hidden agendas.	*Conflict/tension among actors?* **Implementers**: yes = 2. The workers get tense ahead of deadlines, and conflicts occur. There is conflict between landowners and project managers. (Tension occasionally between implementers and community, or implementers and workers). Sometimes private contractors would just show up on site with no communication.

	INFORMATION RECQUIRED		EXAMPLE	DEFINITION	Genius of Space (community members: n=23; implementers: n=8)	Dwars Rehabilitation (community members: n=20; implementers: n=3)
			Joint and integrated authorship of NBS		*Joint ownership?* **Implementers**: yes = 8. Joint ownership to the greatest extent it could be. Vision was for it to be completely community-owned but the funding stopped.	*Joint ownership?* **Implementers**: yes = 2.
			single/divided ownership of NBS		N/A	N/A
	ECONOMIC	RISK	Non-secure financing		*Was funding sustainable?* **Implementers**: no = 7. Unsustainable funding was the main issue for the project. The second phase of the project never received funding, which is the phase that was supposed to generate income for the community. Government led funding which is very short-term and cyclical and it is punitive, if incapable of spending budget allocated within certain time frame, the opportunity to get a similar budget diminishes. To sustain that investement with various challenges faced, towards the end of project became difficult to plot way forward.	Unsustainable funding is a huge challenge, resulting in not being able to pay workers or work to schedule, compromising the project (and leading to loss of workers). *Was funding sustainable?* **Implementers**: no = 3.
		BENEFIT	Possibility for co-financing from other sources		Private sector; *Did you manage to leverage funding/business interest due to the NBS implementation?* **Implementers**: yes = 4 (limited success, very long lag effects).	Private sector; Was there any co-funding from other sources? **Implementers**: yes = 1, an NGO covered the managers salary.
		FINANCIAL SUPPORT	Who pays	Public or private	Public -Provincial Government	Public -National Government (Department of Environmental, Foresrty and fisheries, Natura-Resource Management). Landowners made a contribution as well.
			What kind of costs are supported	Personnel, maintenance, participatory process, communication	**Implementers:** Personnel, maintenance, participatory process, communication, equipment.	**Implementers**: Personnel, training, clothing
			Business model to support private involvement		**Implementers:** Yes = 4, mostly around crowd funding campaigns; support from winefarms (e.g. R1 per bottle goes to community). Numerous marketing, communication campaigns went into trying to attract private sector funding. Unsuccessful for most part. Lack of awareness of community (general public) of the opportunity of NBS.	Yes, the Wildlands Trust model was followed: corporates close to the river were approached. Private landowners can and did participate. The business model means that private sector funding could easily be substituted for government funding, however leveraging private sector funding is the challenge.

	INFORMATION RECQUIRED		EXAMPLE	DEFINITION	Genius of Space (community members: n=23; implementers: n=8)	Dwars Rehabilitation (community members: n=20; implementers: n=3)
	TECHNICAL	LEARNING	Integrating the learning oucomes by actors invloved and their representative organisations for adjustment of NBS, standardisation, producing guidelines, etc.		*Was there any capacity building that happened because of the NBS implementation?* **Implementers**: yes = 7. Several attempts were made, workshops, group meetings, biomimicry teachig and guided walks.	*Was there any capacity building that happened because of the NBS implementation?* **Implementers**: yes = 3. The workers are well trained (first aid, safety, plant identification, herbicide application, firefighting, environmental and financial training). *Integrating learning outcomes by actors involved for adjustment of NBS (i.e. M&E)?* Not done. The implementer has approached academia to assist with research (and monitoring and evaluation).
			Integrating the learning oucomes by actors invloved and their representative organisations for adjustment of NBS in the existing NBS or new NBS		Not done.	Not done.
		CHALLENGES	Challenges like technical uncertainty, hydrology, soil, geology, lack of technical expertise, lack of space or space optimization		*Were technical challenges experienced?* **Implementers:** yes = 4. The socio-economic conditions working in a peri-urban slum was always a risk factor (crime, vandalism, power struggles); space is always an issue in informal settlements, this one which is on a steep slope as well, complicating the installation of infrastructure (complex soils and hydrology).	*Were technical challenges experienced?* **Implementers:** yes = 1. Where skills were lacking, the champion would bring in experts to advise (e.g. issue of secondary invasion).
		LEARNING	Recommendations by community members		**Community:** Continue with the project and assist other sections of the town as well (3), Community members involved would not listen to advice/recommendations, Only people from the pilot area were employed in the project, Vandalism led to failure of the pilot project, Train the right people, better communication and understanding and build a trustworthy network, Work together with the community and employ everyone, Assist all sections with water, The community was not consulted initially, budget could have been better used, More taps & cleaner town needed, More job opportunities desired, Clean drains & environment desired, Our voices were not heard, Desire to install toilets and sewerage, Partner with municipality to leverage more funds, Could have implemented new systems and taught youth, They did not work together.	**Community:** Expand employment from the local community (2), Involve more people, Advise to employ more local people, and respect the opinions of the locals, Notify public about plans, Should clean up after themselves better, Better community engagement upfront (multi-phased), Cut the trees lower, and use more herbicide, Replace equipment; get machines for larger clearing, Plant trees to replace the alien tree clearing, Education and awareness on alien vs indigenous trees

Results

LEVELS/ STAGE	DIMENSIONS	CATEGORY	OUTCOMES/ IMPACTS INDICATORS	Genius of Space (community members: n=23; implementers: n=8)	SCALE OF IMPACT	Dwars Rehabilitation (community members: n=20; implementers: n=3)	SCALE OF IMPACT
	SOCIAL	Cultural	Environmental identity	*Connection to nature improved after the NBS.* **Community:** yes = 14. **Implementers:** yes = 4.	Neighborhood	*Connection to nature improved after the NBS.* **Community:** yes = 16. **Implementers:** yes = 0 (challenging to say, because people value nature differently).	Neighborhood
			Recreational values	*NBS changed how you use nature for recreation?* **Community:** yes = 10. **Implementers:** yes = 1.	Neighborhood	*NBS changed how you use nature for recreation?* **Community:** yes = 14. **Implementers:** yes = 2.	Neighborhood
			Cultural values and practices	*Has the project shaped/changed your cultural values and practices at all?* **Community:** yes = 10. **Implementers:** yes = 3.	Neighborhood	*Has the project shaped/changed your cultural values and practices at all?* **Community:** yes = 10; **Implementers:** yes = 0.	Neighborhood
		Health and well-being	Effects of water quality Effects of water supply	*Has the project improved your health and wellbeing in any way?* **Community:** yes = 16. **Implementers:** yes = 6.	Neighborhood	*Has the project improved your health and wellbeing in any way?* **Community:** yes = 15; **Implementers:** yes = 1 (definitely over time)	Neighborhood
		Improving water related social values and services	Equitable water access for daily use	*Did you find that your access of water for daily use improved after the project?* **Community:** yes = 7. **Implementers:** yes = 2.	Neighborhood	*Did you find that your access of water for daily use improved after the project?* **Community:** yes = 10; **Implementers:** yes = 1 (people do not drink the water).	Neighborhood
			Water availability for different productive uses	*Did water become more available for other uses?* **Community:** yes = 18 (for example: vegetable gardens). **Implementers:** yes = 3 (washing machines, trees, businesses).	Neighborhood	*Did water become more available for other uses?* **Community:** yes = 8 (for example: gardens and farms). There is a perception among roughly half of the people that riverflow has increased. **Implementers:** yes = 1 (the alien tree clearing exposed who was illegally abstracting water)	Neighborhood
			Gender equity	*Did you find improved gender equality after the NBS?* **Community:** yes = 15. **Implementers:** yes = 0.	Neighborhood	*Did you find improved gender equality after the NBS?* **Community:** yes = 3; **Implementers:** yes = 0 (N/A).	Neighborhood
			Crime	*Did you find reduced crime following the project?* **Community:** yes = 7.	Neighborhood	*Did you find reduced crime following the project?* **Community:** yes = 11.	Neighborhood
			Social cohesion	*Did you find improved social cohesion (connectedness, sense of community)?* **Community:** yes = 18.	Neighborhood	*Did you find improved social cohesion (connectedness, sense of community)?* **Community:** yes = 13.	Neighborhood
		Social learning and institutionalisation	Policies related to NBS	*Did any policies on NBS come out following the NBS?* **Implementers:** yes =1 (Yes, It assisted us with doing what we are doing now in Nkanini but not in that particular environment)	Neighborhood, Region	*Did any policies on NBS come out following the NBS?* **Implementers:** yes = 0.	Neighborhood, Region
		Threats identified	Lack of legislation, absence from the state	*Was lack of legislation around the NBS an issue?* **Implementers:** yes = 4.	Neighborhood, Region	*Was lack of legislation around the NBS an issue?* **Implementers:** yes = 0 (There is the NEMA, CARA and Water Act)	Neighborhood, Region

LEVELS/ STAGE	DIMENSIONS	CATEGORY	OUTCOMES/ IMPACTS INDICATORS	Genius of Space (community members: n=23; implementers: n=8)	SCALE OF IMPACT	Dwars Rehabilitation (community members: n=20; implementers: n=3)	SCALE OF IMPACT
		Opportunities identified	Labor, participatory community	*Became more aware of what happened to wastewater.* **Community:** yes = 19. *Was there good community participation?* **Implementers**: yes = 8. *How specifically was community participation encouraged?* **Implementers**: We went through enormous lengths, we had lots of pamphlets, a newspaper, people called with loud-speakers, we had open days, meetings, there was always food and something to drink. We wanted and needed as many people from the community and we needed to understand what ownership meant because we needed to know; Large focus on community engagement, a lot of effort and investment. Door-to-door knocking, with translators, made sure people understood what was happening and make them feel that they could ask questions. Community newspaper print	Neighborhood	*Was there good community participation?* **Implementers**: yes = 3 (on person said there was more 'reaction' than participation); *How specifically was community participation encouraged?* **Implementers**: interviews public advertisments, notices.	Neighborhood
		Mesaures (qualitative/quantitative) showing improvement (augmentation) of water quantity (groundwater, surface water)	Recreational use	(see ecosystem services tab)		(see ecosystem services tab)	
			Aesthetic improvement	(see ecosystem services tab)		(see ecosystem services tab)	
			Social/cultural values for ecosystems and biodiversity	(see ecosystem services tab)		(see ecosystem services tab)	
			Spiritual, symbolic and other interactions with natural environment	(see ecosystem services tab)		(see ecosystem services tab)	
			Tourism (aquatic, farm, Forest)	(see ecosystem services tab)		(see ecosystem services tab)	
			Amount of standing water	N/A		N/A	
			Depth to groundwater	N/A		N/A	
			Water Table Level	N/A		N/A	
			Number of springs recharged	N/A		N/A	
			Streamflow improved/revived	N/A		N/A	
			Other surface water bodies revived e.g. pond, lake	N/A		N/A	
			Streamflow variation	N/A		N/A	
			reduction in groundwater abstraction for human use	N/A		N/A	
			soil moisture (green water improvement)	N/A		N/A	
			increased water availability	N/A		N/A	
			improved groundwater quality	N/A		N/A	
			sediment load	N/A		N/A	
			Turbidity	N/A		N/A	
			Dissolved oxygen cocentration	N/A		N/A	
			Nutrient (N, P) concentration	N/A		N/A	
			Cyanobacteria bloom events	N/A		N/A	
			Biochemical Oxygen Demand (BOD)	N/A		N/A	
			Total coliforms	N/A		N/A	
			Total nitrogen (Kjehldahl N)	N/A		N/A	
			nitrate	N/A		N/A	
			Nitrite	N/A		N/A	

LEVELS/ STAGE	DIMENSIONS	CATEGORY	OUTCOMES/ IMPACTS INDICATORS	Genius of Space (community members: n=23; implementers: n=8)	SCALE OF IMPACT	Dwars Rehabilitation (community members: n=20; implementers: n=3)	SCALE OF IMPACT
		Services	Erosion prevention (% bare ground)	N/A		N/A	
		Ecosystem Services	Food	Increased: Implementers (1), Community (13)	Neighborhood	Increased: Implementers (1), Community (11)	Neighborhood
			Water Provisioning	Increased: Implementers (3), Community (11)	Neighborhood	Increased: Implementers (3), Community (12)	Neighborhood
			Materials	Increased: Implementers (0), Community (6)	Neighborhood	Increased: Implementers (3), Community (12)	Neighborhood
			Energy	Increased: Implementers (0), Community (6)	Neighborhood	Increased: Implementers (3), Community (15)	Neighborhood
			Genetic	Increased: Implementers (1), Community (0)	Neighborhood	Increased: Implementers (1), Community (7)	Neighborhood
			Medicinal	Increased: Implementers (2), Community (8)	Neighborhood	Increased: Implementers (0), Community (6)	Neighborhood
			Ornamental	Increased: Implementers (3), Community (9)	Neighborhood	Increased: Implementers (3), Community (9)	Neighborhood
			Water Purification	Increased: Implementers (6), Community (13)	Neighborhood, Region	Increased: Implementers (3), Community (11)	Neighborhood, Region
			Water Regulation	Increased: Implementers (2), Community (13)	Neighborhood	Increased: Implementers (3), Community (5)	Neighborhood
			Air Quality Maintenance	Increased: Implementers (2), Community (12)	Neighborhood, Region	Increased: Implementers (1), Community (9)	Neighborhood, Region
			Soil Quality Maintenance	Increased: Implementers (4), Community (12)	Neighborhood	Increased: Implementers (2), Community (15)	Neighborhood
			Soil Retention	Increased: Implementers (4), Community (12)	Neighborhood	Increased: Implementers (1), Community (8)	Neighborhood
			Climate Regulation	Increased: Implementers (3), Community (6)	Neighborhood, Region	Increased: Implementers (0), Community (2)	Neighborhood, Region
			Pollination	Increased: Implementers (3), Community (8)	Neighborhood	Increased: Implementers (2), Community (8)	Neighborhood
			Life Cycle Maintenance	Increased: Implementers (0), Community (0)	Neighborhood	Increased: Implementers (3), Community (6)	Neighborhood
			Biological Control	Increased: Implementers (1), Community (2)	Neighborhood	Increased: Implementers (1), Community (6)	Neighborhood
			Recreation	Increased: Implementers (5), Community (9)	Neighborhood	Increased: Implementers (2), Community (14)	Neighborhood
			Science & Education	Increased: Implementers (7), Community (7)	Neighborhood	Increased: Implementers (1), Community (11)	Neighborhood
			Heritage	Increased: Implementers (1), Community (10)	Neighborhood	Increased: Implementers (2), Community (15)	Neighborhood
			Aesthetic	Increased: Implementers (7), Community (15)	Neighborhood	Increased: Implementers (2), Community (17)	Neighborhood
			Symbolic	Increased: Implementers (2), Community (9)	Neighborhood	Increased: Implementers (1), Community (8)	Neighborhood
		Enhancing or conserving biodiversity	Diversity Index	N/A		N/A	
			Composition (aquatic and terrestrial species)	N/A		N/A	
			Presence of bioindicators species (fauna and flora)	N/A		N/A	
			Habitat Conectivity (unitless)	N/A		N/A	
			Aquatic species richness	N/A		N/A	
			Percentage of cover native vegetation	N/A		N/A	
			Benthic organisms	N/A		N/A	
			Percentage of Invasive exotic vegetation	N/A		N/A	
		Income and Jobs	Income generating activities created directly/indirectly	*Did the project create new jobs in your community?* **Community**: yes = 18. *Did your own work situation change due to the project?* **Community**: yes = 14. **Implementers**: yes = 3 (yes during the project, not after the project ended). *Indirectly created jobs through tourism?* **Implementers**: yes = 5.	Neighborhood	*Did the project create new jobs in your community?* **Community**: yes = 13. **Implementers**: yes = 3, (side jobs servicing chainsaws, or providing wood to the community). *Were you directly employed in the project?* **Community**: yes = 10. *Indirectly created jobs through tourism?* **Community**: yes = 3 (recycling, gate keeper); **Implementers**: yes = 0.	Neighborhood
			Jobs created directly/indirectly				
			Property value	*Was there an improvement in property value?* **Community**: yes = 9. Not officially but intrinsically for most people and only for those who were from the area of the pilot. **Implementers**: yes = 1.	Neighborhood	*Was there an improvement in property value?* **Community**: yes = 1. **Implementers**: yes = 1 (property near the river)	Neighborhood

	ECONOMIC		Household income	*If your employment situation changed, was there an improvement in household income?* **Community**: yes = 14. There was an improvement in household income but only during the construction phase. The second phase of the project that was geared towards generating income for the community never realised. **Implementers**: yes = 4 (for those directly employed, yes).	Neighborhood	*If your employment situation changed, was there an improvement in household income?* **Community**: yes = 9; **Implementers**: yes = 0.	Neighborhood
			Other economic benefits	N/A		**Implementers**: reduced fire risk (yes = 2)	Neighborhood, Region
			Water treatment costs	**Implementers**: yes = 5.	Neighborhood, Region	N/A	
			Fertilizers costs	N/A		N/A	
			Water supply costs	N/A		Increased water supply to downstream farms.	Neighborhood, Region
			Irrigation costs	**Implementers**: yes = 5 (less sewage entering rivers; impacts on farmers downstream).	Neighborhood, Region	N/A	

Appendix 4: Supplementary Material to the Global Literature Review (section 2.4)

Table S1. *The code book of the systematic literature review, including all variables collected, its data type, whether it is a categorical or open variable (fixed/free), if it is categorical then the options, and further descriptions. Abbreviations: ID = identifier, NBS = Nature-Based Solution, WRC = Water Research Commission of South Africa.*

Variable	Data Type	Fixed/Free	Description	Options
Case ID	Categorical	Fixed	We assign a number to each case	1-74
Database	Categorical	Fixed	Entries from the global review, or the Global South case study	International, WRC
Authors	Nominal	Free	List the citation	
Year	Categorical	Free	Year of publication	
Title	Nominal	Free	The title of the manuscript of each entry	
Journal/Issue/ Book Name	Nominal	Free	The journal, book, report name	
Literature Type	Categorical	Fixed		Scientific Paper, Book Chapter, Report, Book, Other (describe)
Global South	Categorical	Fixed	Using this list: **http://www.fc-ssc.org/en/partnership_program/south_south_countries**	Yes, No
Country	Categorical	Free		
Location	Categorical	Free		
Scale	Categorical	Fixed	The scale of the NBS project	Local, Regional, National, International, None (Conceptual)
Context	Categorical	Fixed		Urban, Peri-Urban, Rural, None (Conceptual)
Site Characteristics	Text	Free		Describe the site
Timescale Considered	Categorical	Fixed	Considered by NBS project (not the research project): Short-Term (<5y), Medium-Term (6-10y), Long-Term (indef), N/A	Short-Term, Medium-Term, Long-Term, N/A
Timescale Described	Text	Free	Considered by NBS project and the study	Describe the timeframe of the NBS project and the study (start dates, end dates etc)
Type of NBS	Text	Free		Name the NBS (we will try to group these later)
NBS Group	Text	Free	e.g., agroforestry/greening/green infrastructure	Classify the specific type of NBS
Description of the NBS	Text	Free		Describe the NBS
Aim of NBS	Text	Free		Describe the aim of the NBS
NBS Benefit Objective	Text	Free	What was the objective? This could be either an ecosystem service (see list) or anything in addition to this.	The main benefit(s) that the NBS was hoping to achieve.
Objective Met	Categorical	Fixed	Was this objective met?	Yes, No
Co-benefits	Categorical	Fixed	Is the word “co-benefit” mentioned in the publication?	Yes, No
Nomenclature	Text	Free	e.g., additional benefits/co-benefits/indirect benefits/added benefits etc.	A direct quote from the paper that links to the concept of 'co-benefits'
Aim of the study	Text	Free	Describe the aim of the study in terms of the NBS	
Methodological Approach (of the study)	Categorical	Fixed	Method used by the research projec/study: Social surveys on perceptions (e.g., of the value of ecosystem services) is also considered conceptual rather than empirical; Scoring (e.g., from 1-10) is also considered conceptual and not empirical	Empirical, Modelling, Conceptual
Methodological Approach (of the NBS benefits)	Categorical	Fixed	Method used to quantify the NBS benefits: Social surveys on perceptions (e.g., of the value of ecosystem services) is also considered conceptual rather than empirical; Scoring (e.g., from 1-10) is also considered conceptual and not empirical	Empirical, Modelling, Conceptual

Uncertainty Quantified (in the study)	Categorical	Fixed	Any attempt to quantify appropriate uncertainty	Yes, No
Validation performed	Categorical	Fixed	This is for any modelling studies	Yes, No, N/A
Benefits/Costs listed	Categorical	Fixed	Does the study describe any costs or benefits (links to the aim of the study)	Yes, No
Ecosystem Services Benefits/Costs	Categorical	Free	e.g., natural capital, water resources, any of the ecosystem services (see Boerema et al. 2017)	List the Benefits/Costs Described
Direction of impacts on Ecosystem Services	Categorical	Fixed		Positive, Negative, No Change
Societal Benefits/Costs	Categorical	Free	Social/cultural relations or values (e.g., family structures), health (specify what aspects), material assets/physical capital (shelter, energy, sanitation)	List the Benefits/Costs Described
Direction of impacts on Society	Categorical	Fixed		Positive, Negative, No Change
Livelihood Benefits/Costs	Categorical	Free	Income/employment (be specific about the type of employment and how has that changed with the NBS), market access/infrastructure	List the Benefits/Costs Described
Direction of impacts on Livelihoods	Categorical	Fixed		Positive, Negative, No Change
Economic Benefits/Costs	Categorical	Free	Broader economic benefits for society	List the Benefits/Costs Described
Direction of impacts Economic	Categorical	Fixed		Positive, Negative, No Change
Any other Benefits/Costs?	Text	Free	Examples may include: justice (income inequality, participation, knowledge diversity), property rights (e.g., increased/decreased land tenure security)	Describe other Benefits/Costs
Direction of impacts on this other aspect	Categorical	Fixed		Positive, Negative, No Change
Potential Trade-offs	Text	Free	Describe any trade-offs, clearly mentioning which benefits/costs are in conflict	
Are benefits/costs disaggregated by different groups?	Categorical	Fixed		Yes, No, Not Described
Categorisation of disaggregation	Categorical	Fixed	If benefits/costs are disaggregated by different groups, specify this categorisation	Wealth, Gender, Race, Land Ownership, Other (describe)
Displacement of impacts to other locations	Text	Free	Describe whether there is displacement of undesired/desired impacts of the NBS to other locations (See Pascual et al. 2017)	
Barriers	Text	Free	Describe whether there are any barriers to successful NBS implementation (See Sarabi et al. 2019)	
Enablers	Text	Free	Describe whether there are any enablers to successful NBS implementation (See Sarabi et al. 2019)	

Table S2. *The definitions used in this study for the eight different nature-based solutions groups*

Group	Nature-based solution group	Definition
1	Ecosystem protection	Area-based conservation and ecosystem protection approaches including improved management.
2	Restoration/ rehabilitation	This category includes any intervention to assist the recovery of degraded ecosystems (e.g., wetlands, peatlands, riparian zones, terrestrial areas). These interventions are aimed at recovery of a reference condition of the ecosystem, resulting in improved biodiversity and resilience in some cases (restoration), or in recovering ecosystem processes, resulting in the enhancement of the supply of ecosystem services (rehabilitation). Interventions include alien clearing, active revegetation using indigenous plants, reconnecting floodplains, building weirs to stop erosion, implementing buffers, creating detention ponds and attenuation dams, widening the flood zone, changing to flood-compatible land uses, and bank landscaping.
3	Green/blue infrastructure*	In most definitions, green/blue infrastructure refers to a network of interventions/features that aims to solve challenges in developed areas (e.g., urban, peri-urban, industrial) by building with nature, resulting in the provision of ecosystem services to society. For the purposes of this report, green infrastructure didn't need to be an extensive network, but could be one component that could make up this network in practice. Examples of green infrastructure include green roofs, green walls, rainwater harvesting, permeable pavements, alternative building materials and other novel technologies.
4	Bioremediation	Bioremediation is a type of biotechnology which aims to remove contaminants from water or soil through the use of living organisms (e.g., microbes and plants). It includes phytoremediation, bioattenuation and composting.
5	Greening/green spaces	Green space includes land that is partially or completely covered with vegetation (whether grass, shrubs or trees). Importantly green space includes both artificially maintained areas (e.g., parks, community gardens, cemeteries) and wildernesses (e.g., natural ecosystems). This category also includes interventions to expand green space within cities, such as greening and regreening, but importantly not within natural areas. This would fall under the groups: ecosystem protection or restoration/rehabilitation.
6	Agroecosystems/urban agriculture/ecological agriculture*	Agroecosystems and urban agriculture have been combined into one category as they have similar aims and outcomes. Whilst urban agriculture involves the production of food within cities, agroecosystems are defined as ecosystems modified by people to produce food, fibre, fuel and other products for human consumption and processing whilst maintaining

		biodiversity and a supply of a set of ecosystems services to fulfil the needs of current as well as future generations. It is critical to note that agroecosystems can only be considered nature-based solutions if they replace traditional agriculture or transformed land, not if they replace pristine ecosystems. Likewise agriculture, especially traditional agriculture, is not a nature-based solution, however using urban spaces that are highly transformed or otherwise not used for the purposes of agriculture, would result in the production of some provisioning ecosystem services, thereby addressing the societal challenge of food provision, qualifying as a nature-based solution. Ecological agriculture is where environmentally-friendly practices are used, such as no-till, no pesticides/herbicides and no fertilizers are used, and where the soil is not left uncovered, vulnerable to erosion. Again, ecological agriculture is not a nature-based solution in itself. Where replacing a pristine ecosystem, it would be considered habitat destruction, however where replacing already existing traditional agriculture, or when viewed against another alternative (e.g., industry or urban areas), may be considered beneficial in terms of ecosystem service provision.
7	Agroforestry/urban forestry	Although agroforestry and urban forestry differ slightly, they are amalgamated into one category because, like the category agroecosystems/urban agriculture, they have similar aims and outcomes. Whilst agroforestry is a land use management system that aims for diversification, where trees or shrubs are grown around or among crops or pastureland, urban forestry is a practice which involves planting and maintaining the growth of trees and plants within urban areas. Both aim to provide an increased suite of ecosystem services to society, which differ from traditional forestry practices. Like with agricultural, it is likewise critical to note that agroforestry can only be considered a nature-based solution if it replace traditional agriculture or forestry, not if it transforms a pristine ecosystem.
8	Combination	Any combination of two or more NBS groups listed here.

* There may be some overlap between green roofs and urban agriculture where the green roofs are used for food production. However we kept these as distinct entities and didn't combine them into the category "combination", as they are still quite specific and not as holistic as the approaches used in the combination category.

Table S3. *The details of each of the nature-based solution (NBS) types that were included in each nature-based solution category in the review of peri-urban nature-based solution publications.*

NBS Group	Details
Agroecosystems/urban agriculture	Integrated catchment management, ecological agriculture; Orchards and vineyards in New Zealand with environmentally friendly practices, when considered against the alternative: urbanisation; Urban farms; Urban and peri-urban agriculture; Urban landscapes for food production; Urban allotments (small private gardens); Ecosystem services provided by agroecosystems
Agroforestry/urban forestry	Urban and peri-urban agroforestry systems; Forest areas near urban or peri-urban areas for recreation; Agroforestry: forestry with indigenous tree species, also exploring mixed species/mixed aged tree systems; Mixed agroforestry systems; Tree planting; Forests and green spaces in urban and peri-urban areas
Bioremediation	Submerged/rotating bio-contactors and artificial wetlands; Wastewater management - wastewater biorefinery; Water Purification through ultrafiltration, with cleaning of the membrane through fungal enzymes (more environmentally friendly approach) rather than chemical cleaning; Biological remediation of return flows into a dam; Biotechnology-based potential for integration in the management of salinity and sanitation waste via algal ponding; Constructed wetlands (various types); A semi-closed horizontal tubular photobioreactor for wastewater management
Combination	Enhancement of ecological connectivity, ecosystem restoration, revegetation, improved balance (quarry activities and biodiversity conservation), traditional agricultural conservation, banks stabilisation, floodplain restoration; Green infrastructure, agroforestry, and regreening; Green infrastructure and urban planning: reserving urban space for forests, building green roofs and walls, development and expansion of the water drainage system network, energy efficiency; Artificial wetlands, rehabilitation and protection of natural wetlands, clearing of invasive alien plants; Drought mitigation and adaptation (e.g., green infrastructure, rainwater harvesting, wetlands); Sustainable planning for peri-urban landscapes via urban forestry and urban agriculture, Sustainable urban drainage systems, Green spaces; Green infrastructure for stormwater and water quality management: grassed swales, rain barrels, dry ponds, wet ponds, green roofs (with rain cisterns), porous pavements; Green infrastructure (Gorla Maggiore water park): constructed wetlands, green spaces (biodiversity and recreational area); Green space and green infrastructure; Green spaces, roof gardens, green walls, green parking, permeable surfaces, planting of small gardens, green corridors to nature reserves, renaturalization of river bed, phytoremediation, phytodepuration system
Ecosystem protection	Conservation planning, water resource planning and local estuary management and planning; Improved conservation of key water source areas
Green infrastructure	The use of Typha (a wetland reed) as an alternative (high value, green) interior architecture building material; Residential rainwater harvesting in tanks; Rooftop greenhouses; Rooftop farms (some hydroponic), rainwater harvesting; Constructed treatment wetlands and enhancement of pollination on unused land; Green spaces and stormwater management; Higher permeable cover at the neighbourhood scale (e.g., trees, gardens etc)
Green spaces	Green spaces (public and private) in a city; Nature/green spaces in peri-urban areas; Green space and parks in urban environments;

	Phytoremediation by green spaces (moss turfs and an Australian tree species); Open spaces/natural areas compared along a rural-urban gradient (i.e. by quantification and valuation techniques); Forested areas and green spaces; Trees and gardens in a city; Public park, lawns, scattered trees and villas, agricultural fields, pastures, forests, lakes, wetlands, golf course
Restoration/rehabilitation	Restoration of natural capital; River rehabilitation; Rehabilitation of aquatic ecosystems; Invest in ecological infrastructure (e.g., the rehabilitation of upstream catchments); Protection and/or restoration of ecological infrastructure; Restoring priority streams and rivers in the Municipality; Wetland rehabilitation; Wetland rehabilitation: assisting in (1) the recovery of a degraded wetland's health and ecosystem service delivery by reinstating the natural ecological driving forces, or (2) halting the decline in the health of a wetland that is in the process of degrading, so as to maintain its health and ecosystem service-delivery

Table S4. *Ecosystem services of peri-urban nature-based solutions derived from the literature, including codes and the number of mentions.*

Ecosystem Services	Code	Number
Aesthetic Services	A	25
Air Quality Regulation	AQ	19
Biological Control	BC	2
Climate Regulation	CR	32
Energy & Fuel Production	EF	11
Food Provision	FP	25
Genetic Resources	GR	8
Heritage, Cultural, Bequest, Inspiration & Art	H	11
Life Cycle Maintenance	LC	16
Materials & Fibre Production	MF	10
Medicinal Resources	MR	3
Noise Regulation	N	1
Ornamental Resources	OR	4
Pollination	P	6
Recreation & Tourism	RT	30
Scientific & Educational Services	SE	14
Soil Quality Regulation	SQ	11
Soil Retention	SR	18
Symbolic, Sacred, Spiritual & Religious Services	S	8
Water Provision	W	19
Water Purification	WP	35
Water Regulation	WR	46

Table S5. *Benefits of peri-urban nature-based solutions derived from the literature, including categories, descriptions, codes and the number of mentions.*

Category	Benefit	Code	Description	Number
Economic	Circular economy	E_S	Green economy/sustainable use	7
	Cost effectiveness	E_C	Cost effectiveness of the NBS	34
	Economic growth	E_G	Economic growth	11
	Industry growth	E_IG	Growth of supporting industries (agriculture/ tourism/ fishing/etc)	8
	Infrastructure	E_I	Improvements to infrastructure	5
	Job creation	E_J	Job creation	12
	Market/commodity	E_M	Market priced benefits/costs (e.g., commodity products produced)	8
	Revenue	E_R	Revenue/ economic viability/ economic savings	5
Livelihood	Employment/income	L_E	Income/employment	22
	Justice	L_J	Justice (income inequality/equality, environmental equality, participation, knowledge diversity)	3
	Poverty alleviation	L_P	Poverty alleviation	3
	Property rights	L_PR	Property rights (e.g., increased/ decreased land tenure security)	3
	Property value	L_PV	Property values increased/decreased	9
Societal	Education	S_E	Education (specify what aspects)	22
	Energy security	S_ES	Energy security	2
	Food security	S_FS	Food security	16
	Good governance	S_G	Good governance	5
	Health & well-being	S_H	Health, Sanitation, Well-being (mental/emotional/spiritual/physical), Standard of living / socio-economic development/ quality of life / social sustainability	60
	Safety	S_SF	Safety (security and risks)	18
	Social cohesion	S_SC	Social cohesion/cultural relations or values (e.g., family structures)	14
	Water security	S_WS	Water security	15

Table S6. *The main benefits (objectives) of the peri-urban nature-based solution for each category of nature-based solution.*

	Agroecosystems/ urban agriculture	Agroforestry/ urban forestry	Bioremediation	Combination	Ecosystem protection	Green infrastructure	Green spaces	Restoration/ rehabilitation
Aesthetic Services	0	0	0	1	0	0	3	0
Air Quality Regulation	0	3	1	0	0	0	3	0
Biodiversity	0	0	0	3	1	0	1	0
Climate Regulation	1	2	0	1	0	0	3	0
Ecology	0	0	0	1	1	0	0	2
Economic growth	0	0	0	0	0	1	0	0
Ecosystem Services Provision	3	1	0	1	1	0	0	3
Education	1	0	0	0	0	0	0	1
Employment /income	0	1	0	0	0	0	0	0
Energy & Fuel Production	0	1	0	0	0	0	0	0
Food Provision	2	1	0	0	0	2	1	0
Habitat Creation	0	0	1	0	0	1	0	0
Health & well-being	3	1	0	0	0	0	4	0
Improve land use	1	0	0	0	0	0	0	0
Improve livelihoods	0	1	0	0	0	0	0	0
Job creation	0	0	0	0	0	0	0	1
Justice	0	0	0	0	1	0	0	0
Materials & Fibre	0	1	0	0	0	0	0	0
Nature Experience	0	0	0	0	0	0	1	0
Noise Regulation	0	0	0	0	0	0	1	0
Pollination	0	0	0	1	0	1	1	0
Recreation & Tourism	0	1	0	0	0	1	4	0
Safety	1	0	0	0	0	0	0	1
Scientific & Educational Services	1	0	0	0	0	0	0	0
Social cohesion	1	1	0	0	0	1	1	0

Soil Quality Regulation	1	0	0	0	0	0	0	0
Soil Retention	0	0	0	0	0	0	0	2
Symbolic, Sacred, Spiritual & Religious Services	0	0	0	0	0	0	2	0
Technology developmen t	0	0	1	0	0	0	0	0
Water Provision	0	1	0	2	0	1	0	2
Water Purification	0	0	7	5	1	2	0	5
Water Regulation	1	1	1	4	0	3	3	1

Table S7. *Summary of the barriers and enablers of peri-urban nature-based solutions.*

	Category Name	Detailed Name
Enablers	Economic instruments, finances	Economic Instruments, Finances
	Knowledge generation	Education, Training, Research, Knowledge, Experience
	Innovation & technology	Innovation, Technology, Experimentation
	Stakeholder engagement & collaboration	Partnership, Collaboration, Stakeholder engagement, Stakeholder willingness, Trust, Communication
	Planning, governance, policy	Planning, Governance, Policy
	Resources, potential	Resources, Potential
Barriers	Degradation	Climate change, Disasters, Ecological degradation, Decreasing natural resources
	Complexity	Complexity
	Financial issues	Cost, Inadequate financial resources, Issues internalising value, Financial instability, Market forces
	Inadequate regulations	Inadequate regulations (policy, legislation, directives), Legal barriers
	Social vulnerability	Inequality, Segregation, Lack of access, Gentrification, Vulnerability, Lack of property rights
	Governance challenges	Institutional fragmentation, Government incompetence, Deficiencies in management structures, Lack of stakeholder engagement, Lack of enforcement, Path dependency, Failing infrastructure
	Lack of data/technology	Limits to: Data, Research, Technology, Evidence
	Lack of capacity/skills	Skills deficit, Lack of capacity
	Space & times limits	Space and Time Limits
	Stakeholder issues	Stakeholder path dependency, Human behaviour, Lack of: support, willingness, trust, cohesion, Unsustainable/Illegal activties, Land ownership issues, conflict
	Urbanization & development	Urbanization, Urban sprawl, Population growth, Development pressures, Fragmentation, Densification, Urban primacy, Immigration, Land-use change

Table S8. *Detailed descriptions of the barriers and enablers of peri-urban nature-based solutions.*

	Category Name	Descriptive Name	Details
Enablers	Economic instruments, finances	Economic Instruments, Finances	Economic (there is a growing market); Economic incentives; Financial support (The need to safeguard privately owned forest with high recreational value is reflected in a newly implemented policy that allows landowners to make voluntary agreements to protect forests with high recreational values and provides compensation for missed income from harvesting); Funding (C40 Climate Finance Facility); Funding (has been secured); Funding provided by state (e.g., State Government committed $20 million over four years for Park Lands revitalization projects through its Planning and Development Fund); Growth of urban centers; Investment by local parks board to improve parks ($300 million over the next 20 years); Large resource investments; Local investments and incentives provided by the government; Strong financial support from government; This process attracted funding and a training course was developed; Thriving economy
	Knowledge generation	Education, Training, Research, Knowledge, Experience	Academic research can and does enable changes in the wastewater industry; Experience; Extensive knowledge on ECS technologies; Extensive research/knowledge on positive relationship between nature, sustainability, and health and well-being; National Resource Management programmes have been largely successful; Opportunity for environmental education to preserve urban green areas
	Innovation & technology	Innovation, Technology, Experimentation	Combining NBS with other urban elements and grey infrastructures (e.g., green walls); Design flexibility of wetland technology (allows for innovative approaches for wetland integration in the urban environment, e.g., on river boats, compact/mobile units, top of buildings, in roundabouts, roofs etc); Effectiveness, innovation and diversification for the local food system; Innovation; Innovation; Innovation (there is the opportunity to develop products that will add value); Innovation and experimentation; Innovation and technology; Innovation to enhance access of the poor to land to improve food security; Scenario-planning tool to support local governments (to plan for low-carbon-emissions development pathways that seek economic growth opportunities while contributing to national targets for emission reduction); Technological advances; Technological innovation; Technological innovation (i.e. GIS- and remote sensing data, including public participatory GIS and the use of mobile phone apps, and big data can be used to gather information about cultural ES; Technologies and communication among publics and actors; Technology: use of a biophysical foot printing approach will enable producers to demonstrate to retailers and consumers the impact that their production is having on the local water resources and carbon emissions.; The “One Million-Mu Plain Afforestation Project” made progress with an innovative strategy to motivate farmers, i.e. renting land from farmers and recruiting them as gardening workers

	Stakeholder engagement & collaboration	Partnership, Collaboration, Stakeholder engagement, Stakeholder willingness, Trust, Communication	A community of practice has been established in the catchment which includes hybrid EI interventions, social learning through participatory practices, the co-production of knowledge and data, community-based practices for water and climate governance and climate adaptation, experimentation with EI interventions in the catchment, and an action plan; Actors involved (Multistakeholder approaches in bottom up - top down hybrids); Bridging knowledge and communication gaps between individuals and institutional actors.; Citizen pressure (rising expectations for environmental quality of its growing middle class); Collaboration; Collaboration (urban farms represent a partnership of mutual commitment between farms and communities of users/supporters) ; Collaboration among stakeholders (Catchment Management Programme, Farmer Support Group, government, research institutions, the private sector and a host of local groups and organisations); Collaboration of local governments (creating places of social and environmental quality for different social groups); Community interest (they are starting to expand their efforts to integrate green infrastructure to move toward more sustainable low impact water management); Community relationships; Determined local people; Increased cooperation between academia, state entities and industry on specific technologies in SA; International partnerships; Involvement of local people; Knowledge sharing between citizens in urban gardening projects & partnership of stakeholders (i.e. municipality and citizens in allotment garden schemes); Multiple stakeholders are involved in the partnership; Negotiation, cooperation, and coordination processes with project partners and stakeholders; Partnership of stakeholders to increase resilience of the urban-rural landscape; Partnerships between institutions; Perceptions (people are concerned about reductions in catchment water yields and want to limit exotic plantations); Reconnection between farmers and consumers and people and nature; Residents have strong willingness to participate in green spaces governance.; Stakeholder collaboration (working together); Stakeholder engagement; Stakeholder engagement (between urban farmers, communitarian organizations, NGOS, municipality and academia); Stakeholder engagement (considerable interest from farmers and community members due to potential for job creation resulting from operation of small plants for groups of people) ; Stakeholder engagement (partnerships); Stakeholders willingness to invest in rehabilitation; Strong involving and activating momentum due to basic needs; Willingness of landowners to get involved and to improve communication; Willingness of the city to strengthen its green image and expand green spaces

	Planning, governance, policy	Planning, Governance, Policy	Adaptation is already present in spatial and urban planning in Serbia; Constitution (Ecuador's new constitution recognises the "Rights of Nature"); Effective planning; Favourable legislative framework for the integration of urban agriculture in urban development master plans; Good legislative tools; Institutions, norms and policies; Legislation (SA has a series of national environmental policies and legislation (e.g., NWA, NEMA, CARA) that make provision for mandatory restoration projects); Legislation (the Myanmar government has embarked on an effort to transition to a green economy); Mandates: the national water authority carries a unique responsibility to promote the growth of self-regulating catchment management; Planning, governance, acts and legislations (Targets incorporated in the EU Biodiversity Strategy for 2020); Policy (The EU Biodiversity Strategy have set specific policy targets for maintaining and enhancing ecosystems and their services by establishing green infrastructure and restoring degraded ecosystems); Some strong institutions; Strategies and plans and governance; Strong leadership; Strong local governance; Support (easy to implement because the council is supported by the neighbourhood owners' representatives); Supportive legislation for rehabilitation of wetlands; Supportive policy context (European Commission - 7 R&I Actions recommended); Supportive policy framework; Synergies with local food initiatives of the EU; The involvement of multiple governmental agencies and an interactive hierarchical system formed a central coalition to support the leadership; The state restoring over 3000 m2 of green space (train going below ground)
	Resources, potential	Resources, Potential	Abundant growth of Typha; Community gardens - stakeholders are guaranteed weekly deliveries of seasonal produce; High availability of surface water area not only motivates the presence of a fishery industry, but also provides recreational opportunities; High potential (from an environmental connectivity point of view); Highly productive agricultural sector; Integrated Approach (combined potential for wealth creation, upskilling and job creation in a region or community can motivate for its efficient operation by that region or community, prioritising it over the less tangible water treatment); Investment (the potential for value generation may assist in motivating investments); Job creation; No real shortage of land in most cities; Opportunities for integration between economic development, nature valorisation and public health promotion; Potential for indigenous tree market to grow; Practical and financial feasibility; Well-managed sites
Barriers	Degradation	Climate change, Disasters, Ecological degradation, Decreasing natural resources	Climate change (and how to adapt); Disaster risk reduction; Ecological degradation; Ecological preservation; Decreasing water resources; Regular supply of water; Risk due to declining water quality, which may not meet the high standards set for irrigation water by these international markets (international certification); Uncoordinated development and inappropriate land use have resulted in environmental degradation as has deforestation, expansion of informal settlements, erosion, dune denudation, pollution of watercourses, alien vegetation and illegal dumping; Water scarcity

	Complexity	Complexity	Challenges of peri-urban areas: dynamic, complex thus difficult to come up with a single approach for planning and management; Challenging environmental conditions; Complex actor groups; Complex environmental challenges; Complex land tenure systems; Complexity of rural and urban land management in areas under Traditional Authority; Underestimating complexity
	Financial issues	Cost, Inadequate financial resources, Issues internalising value, Financial instability, Market forces	Cost of implementing green infrastructure practices are very high; Economic (limited financial resources thus poorly maintained wastewater treatment works); Economic challenges (to internalise ecological infrastructure and ecosystem services within the development potential of economic systems); Ecosystem services are underestimated in local spatial planning; Financial instability; Inadequate financial resources; Inappropriate price of water (insufficient to sustain re-investment in water resource systems); Incorrect valuation (partial valuation of the direct use value added by the rehabilitation, thus an under-representation of the economic value of the wetland rehabilitation); Invasive vegetation is expensive to clear; Lack of investment/finances; Lack of understanding of ecosystem or biodiversity values (can lead to distorted decision-making); Limited funding; Limited resources; Market challenges: sourcing, availability and reliability of supply, quality variation, transportation; New products and markets need to be developed; Resource availability (financial); Stability of employment is not guaranteed; Unpredictable market demand for indigenous trees; Unsustainable financing systems; Market uncertainty; Capital investment (finances)
	Inadequate regulations	Inadequate regulations (policy, legislation, directives), Legal barriers	Absence of clear and efficient urban development policies that allow integral development; Absence of clear directives about how to implement good legislation and policy; Building code regulations (prohibit GI such as rainwater harvesting from taking place); Gap in policy (private allotments are treated differently to public allotments as open space in planning policy); Lack of integration of nature-based solutions into the urban planning process and of support through urban policies; lack of legislative framework for package plants; Lack of official legal protection of forests; Lack of policy support (in the context of the promotion of adaptation as a primary goal or as an integral part of the strategies or within sectorial urban thematic issues); Lack of pro-active management policies; Legal barriers for market uptake of nature-based solution productions; Legislation (national environmental policies and legislation internalise the costs and benefits of restoration activities and thus fail to change the economic drivers that generate the need for restoration); Many by-laws, policies and procedures are outdated; Non proactive policy; Policy constraints; Poor building standards; Poor policy (laissez-faires (“allow to do”) policies); Prohibitive legal clauses/legislation; Restrictions on native vegetation clearance around dwellings have been weakened so that residents are now allowed to clear vegetation 20m from their dwelling, thereby potentially adversely affecting environmental assets in the rural-urban fringe.

	Social vulnerability	Inequality, Segregation, Lack of access, Gentrification, Vulnerability, Lack of property rights	High inequality economy; High rates of socio-spatial segregation; Lack of access to credit by farmers adds to their ability to cope with the multitude of other pressures; Gentrification; Green gentrification; Socioeconomic transformation; Vulnerable to change; Inadequate access to good quality irrigation water; Property rights (lack thereof); Resolving wetland access and tenure, identifying business owners, employees and services providers (potential role/responsibility conflict); Uncertainty about property rights
	Governance challenges	Institutional fragmentation, Government incompetence, Deficiencies in management structures, Lack of stakeholder engagement, Lack of enforcement, Path dependency, Failing infrastructure	Backlogs in the development of water supply and sanitation infrastructure and services, Inadequate maintenance of water infrastructure; Deficiencies exist in management structures; Development of a system for adaptation is still not recognized as a priority.; Farm abandonment due to political changes; Fragmentation between national and provincial levels of government; Fragmented Government Mandates; Governance challenges; Governance implementation constrained by lack of strong local leadership; Incorrect vision (emphasis on recreation instead of downstream beneficiaries); Institutional fragmentation ("siloed" agencies and professional disciplines constrain cooperatively implementing green networks); Lack of clearly defined roles and responsibilities between local and national governments; Lack of national directives that include both 'carrots and sticks' to encourage implementation, and lack of local ordinances to make GI easier to implement); Lack of cooperation with local citizens; Lack of enforcement; Lack of governance (involvement of the national and provincial departments of agriculture); Lack of mainstreaming knowledge on Edible City Solutions technologies, experiences and provided ecosystem services; Lack of maintenance of drainage systems caused by economic contraction; Lack of political will (to apply regulations and by-laws by authorities responsible for the catchments); Lack of support (in promotion of adaptation as a primary goal); Lax enforcement (Uncontrolled peri-urban areas); Legal obligations are not being adhered to or enforced; Little government support; Mechanical breakdowns; Metering and revenue collection systems are inefficient; Landscape architects and planners paradigms (need to stop managing and engineering water out of our urban environments, and instead work creatively to design places and mechanisms which re-establish self-regulating natural water cycles); New planning provisions (changing attitudes of government); Non proactive management; Path dependencies (Built Infrastructure is strongly entrenched and difficult to shift due to apartheid and colonialism legacy); Political will; Poor city planning in the past; Poor design and operation of private treatment systems; Poor enforcement (lack of control of government over land-use); Poor infrastructure (sewerage systems get blocked and overflow into rivers); Poor leadership, management; Resistance of decision makers to change; Siloed institutions; Slow municipal service provision (poor infrastructural development); Technical and financial governance (budgetary and expenditure problems); The municipal disaster management centre is poorly resourced and poorly funded; Top-down administration system have extensively retrained the power of non-governmental actors

	Lack of data/technology	Limits to: Data, Research, Technology, Evidence	Absence of acceptance of Edible City Solutions esp. in vulnerable groups and abandoned areas; Data on the removal capacity of microalgae based systems under real conditions is still scarce; Gap in research (lack of information on ownership and spatial extent); Lack of economic data; Lack of explicit evidence of the salutogenic benefits of nature. ; Lack of large-scale data and information; Lack of relevant data; Lack of sufficient data to inform economic decisions; Lack of technology and information (few commercially successful examples were available); Lack of tools and data to inform management about user needs and values; Lagging technological adaptions; Limited data; Limited development of package plant technologies; Pilot plants have not yet been implemented; Poor data to support municipal decision-making; Technical (implementation can be influenced by construction difficulty); Uncertainty on potential health risks of Edible City Solutions products; Product quality
	Lack of capacity/skills	Skills deficit, Lack of capacity	Education (lack of technical capabilities to adequately maintain and upgrade wastewater treatment works); Inadequate skills and low investment; Lack of expertise; Lack of expertise (shortage of Limnologists); Lack of knowledge (most people were unfamiliar with the technology); Lack of knowledge (uncertainty on how to monitor greenspaces); Lack of scientific rigour; Lack of skilled personnel; Lack of technical and managerial expertise; Lack of technical capacity and skills; Lack of water resource education; Poor operational skills and lack of maintenance of privately owned sewage treatment systems; Poor skills; Resource availability (human)
	Space & times limits	Space and Time Limits	Inadequate time for planning that caused an absence of rules during the project implementation; Lack of land; Limited space; Limited space (restricts development of NBS); Space (limited suitable locations to implement); Space limitations to expand urban forests; The high cost of restoration together with the time lag before benefits are realised makes restoration activities unprofitable for private entities in most cases; Time scales and other key features of interventions need to be delineated
	Stakeholder issues	Stakeholder path dependency, Human behaviour, Lack of: support, willingness, trust, cohesion, Unsustainable/Illegal activities, Land ownership issues, conflict	Behaviour of people is hard to change; Changing attitudes of locals (younger members of the community showed less interest in farming compared to the past); Dependent on programs from elected city council; Difficulty in changing behaviour; Lack of community cohesion; Environmental risks with harvesting (unsustainable harvesting)/enforcement of this; Illegal activities (dumping sites); Land ownership (municipal responsibility for recreational opportunities for residents, but land owned by private entities); Misunderstanding among residents that this private allotment had the same level of protection as a municipal site; Needs, obstacles, and facilitating processes and associated transitions and path dependencies need to be clarified; Possibility of conflict over land-use or funding; Risk Aversion (industries unwilling to share information due to proprietary concerns); Stakeholder engagement (public participation willingness); Sustainable harvesting (under pressure from extractive use)

	Urbanization & development	Urbanization, Urban sprawl, Population growth, Development pressures, Fragmentation, Densification, Urban primacy, Immigration, Land-use change	Cities with a monocentric development; Development pressure; Fragmentation; Fragmentation of woodlands; Functional transformation and densification trends; Growing human population; High degree of urban primacy; Immigration into communities; Urban sprawl; Urbanization; Urbanization (rapid urban development); Extensive land use change in urban and peri-urban areas has taken a toll on urban and peri-urban agriculture in many cities.; Increased pressure from the growing community on the water resource; Increasing energy use; Land-use change; Population increases; Positive correlation between population growth and proximity of green spaces (development can generate more demand), resulting in urban sprawl; Pressure of human population density is high; Prior developments that now constrain options for future greening; Tourism; Urban expansion; Urban growth disjointed in the periphery of cities

Table S9. *The categories of displacement as well as descriptions for peri-urban nature-based solutions*

Displacement Category	**Description**
Downstream erosion	Protection of downstream areas from erosion
Downstream flooding	Reduction of flooding downstream
	Protection of downstream areas from flooding
	Protection of downstream areas/infrastructure from flooding/other risks
Downstream water quality	Downstream water quality
	Downstream water quality (no nutrient waste due to water runoff)
	Improvement in downstream water quality
	Preventing pollutants from overflowing into the river
	Protection of downstream areas/infrastructure from sedimentation/other risks
	Restoring ecological infrastructure in one place leads to improved water quality downstream
General ecosystem services	Improved delivery of ecosystem services in another place
	Restoring ecological infrastructure in one place leads to improved delivery of ecosystem services in another place
	Water flows out of upland areas provide multiple ecosystem services to downstream areas

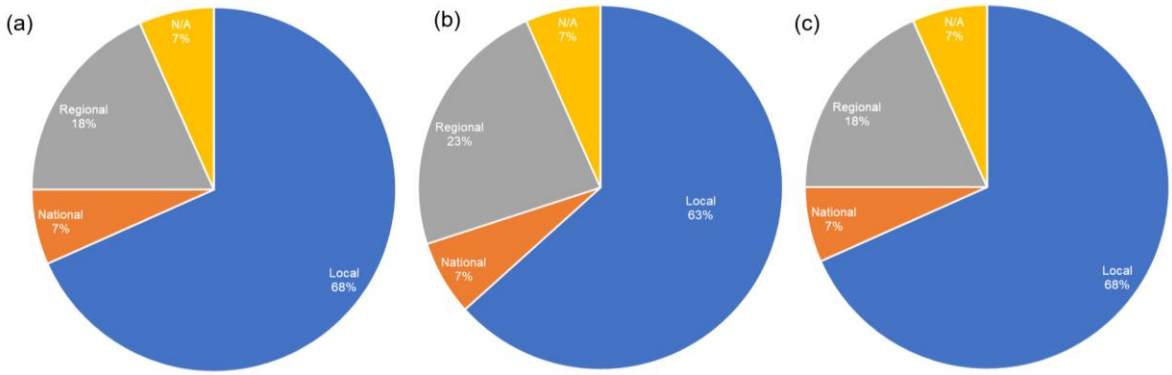


Figure S1. *The focus scale of the nature-based solution projects: international, national, regional, local and not-applicable (N/A), which is where studies were theoretical, and no scale/potential scale was specified. Graphs are: (a) for all studies, (b) for Global South studies only and (c) for Global North studies only.*

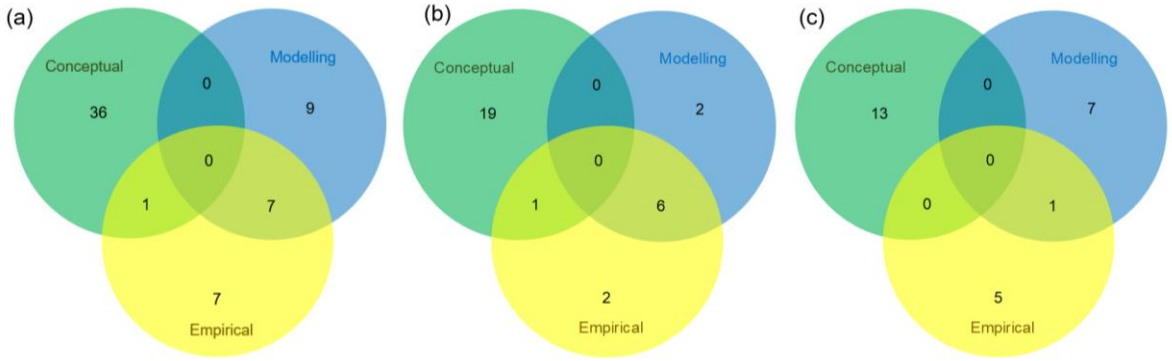


Figure S2. *Venn diagrams of the methodologies used to quantify the benefits of the nature-based solutions: conceptual, modelling and empirical, and various combinations (n=60). Graphs are: (a) for all studies, (b) for Global South studies only and (c) for Global North studies only.*

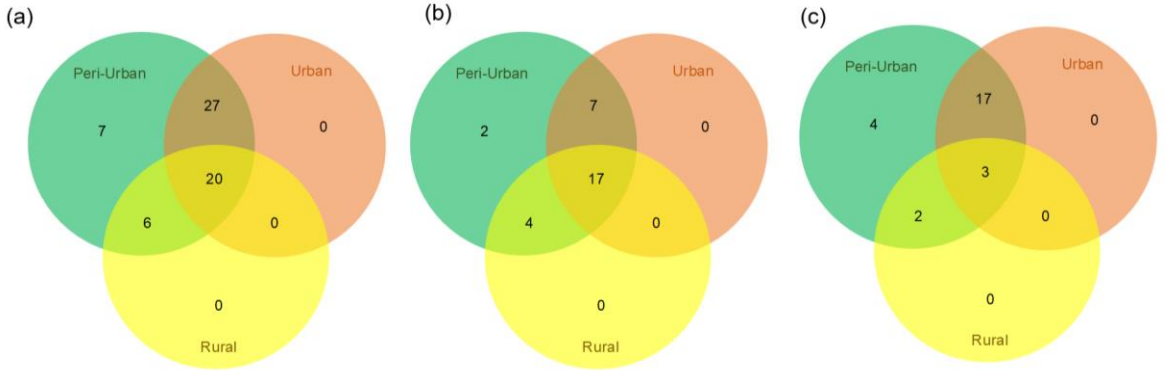


Figure S3. *Venn diagrams of the different study contexts: peri-urban, urban, and rural, and various combinations overall (n=60). Graphs are: (a) for all studies, (b) for Global South studies only and (c) for Global North studies only.*

Appendix 5: Supplementary Material for section 3.1.2

SUPPLEMENTARY MATERIAL S1 – species list

**List of alien weeds, shrubs, and tree species within the Dwars River riparian zone. Species lists were provided by Cape Nature and the Wildlands Trust. These lists were supplemented by sightings captured on iNaturalist*

Shrubs / trees	
Acacia dealbata	Silver Wattle
Acacia longifolia	Longleaf Wattle
Acacia mearnsii	Black Wattle
Acacia melanoxylon	Blackwood
Acacia saligna	Port Jackson
Alnus glutinosa	Common Alder
Eriobotrya japonica	Loquat
Eucalyptus	Eucalytpus
Ligustrum sinense	Chinese Privet
Melia azidarach	Syringa
Paraserianthes lophantha	Stink Bean
Pittosporum undulatum	Sweet Pittosporum
Populus × canescens	Grey Poplar
Populus alba	White Poplar
Quercus nigra	Water Oak
Quercus robur	English Oak

Alien weeds	
Amaranthus cruentus	Red Amaranth
Araujia sericifera	White Bladderflower
Arundo donax	Giant Reed
Avena barbata	Slender Wild Oat
Briza maxima	Greater Quaking Grass
Canna glauca	Water Canna
Carduus pycnocephalus	Italian Thistle
Catharanthus roseus	Madagascar Periwinkle
Chenopodium album	Common Lamb's-Quarters
Cirsium vulgare	Bull Thistle
Colocasia esculenta	Taro
Complex Rubus fruticosus	European Bramble Complex
Datura stramonium	Common Thornapple
Echium plantagineum	Paterson's Curse
Foeniculum vulgare	Fennel
Genista monspessulana	French Broom
Hypochaeris radicata	Common Cat's-Ear
Lantana camara	Lantana
Lonicera japonica	Japanese Honeysuckle

Lupinus angustifolius	Narrow-leaved Lupin
Melia azedarach	Chinaberry
Nasturtium officinale	Watercress
Oenothera biennis	Common Evening-Primrose
Paraserianthes lophantha	Plume Albizia
Pennisetum clandestinum	Kikuyu Grass
Phytolacca americana	American Pokeweed
Plantago lanceolata	Ribwort Plantain
Pontederia cordata	Pickerel Weed
Rubus flagellaris	Bramble
Rumex crispus	Curled Dock
Solanum mauritianum	Bugweed
Sorghum halepense	Johnson Grass
Tradescantia fluminensis	Small-leaf Spiderwort
Tradescantia fluminensis	Small-Leaf Spiderwort
Tradescantia zebrina	Wandering Jew
Trifolium repens	White Clover
Verbena bonariensis	Purpletop Vervain
Xanthium strumarium	Rough Cocklebur

SUPPLEMENTARY MATERIAL S2 – Interview schedule

Introduction

During this interview, I will be asking you some questions about your background, your interaction with the Dwars River, your relationship with the community and your opinion on ecological restoration. I hope to use this information to help those who are involved in the restoration of the Dwars River, to better understand what landowners and members of the neighbouring communities want to gain from the river.

Topic 1: General information about property

1.1 How many years have you owned, managed or lived on this property?
1.2 Do you make decisions about how to manage the land on this property?
1.3 Of the following options, how would you describe this property:
Would you say it's a ….
i. Large-scale farm with more than one type of crop
ii. Small-scale farm with only one type of crop
iii. Household with a garden
iv. If other, please explain
1.4 (*Question not applicable if the property is a house*)
If you know, approximately how many hectares is this property?
1.5 Do you know if the land was farmed before you moved to the property?
a. If yes - what was it?

Topic 2: Interaction with the Dwars River

2.1 Has this section of the river flooded in the time that you have lived here?
a. ***If yes***, can you recall when it last flooded?
2.2 Is the health of the river a concern to you? (*Prompt - just to clarify, river health in this instance means that it is in a good condition. Sewerage flowing into a river would be an example of a river with poor health*).
a. Why?

Topic 3: Relationship with the surrounding community

3.4 (*Question not applicable if the property is a house*)
Are you involved with the surrounding community in any way? *(community projects etc)*
3.5 (*Question not applicable if the property is a house*)
Are there any parts of your land that the public can access?
a. *If yes* – please elaborate

Topic 4: Knowledge on invasive alien species

4.1 Do you know what an invasive alien plant is?
If no *- Just to clarify, invasive alien plants are species that establish and spread in areas where they do not naturally occur. For example, Port Jackson and Black Alders are invasive alien plants.*

4.2 Do you believe that all invasive alien plants are detrimental to nature?

4.3 How familiar are you with the work of the Wildlands Trust in this region?

a. Very familiar - know of their work and have interacted with them
b. Fairly familiar - know of their work, but have never interacted with them
c. Vaguely familiar - heard of them but unsure of what they do
d. Not at all familiar - have never heard of them

4.4 Have any alien invasive clearing activities taken place along the river on your land that you are aware of?

If yes:

a. How recently did this occur?
b. Has the contracted company come back several times to conduct further clearing or was it a once-off operation?
c. Have you noticed any changes to the river since the removal of the alien species?

If yes – have you noticed any of the following changes?

a. There is more water flowing in the river
b. There have been fewer fires surrounding the river
c. The river is cleaner and less polluted
d. More people from the community are interacting with the river than before
e. Other - please specify

4.5 Please select the option that applies to you – clearing of invasive alien plants on private land should be the responsibility of:

a. Solely the landowner
b. Solely the government
c. Primarily the landowner, with assistance from the government
d. Primarily the government, with assistance from the landowner
e. Equal partnership between the land-user and the government
f. Other (please specify)

Topic 5: Knowledge of ecological restoration

5.1 Are you familiar with the term 'ecological restoration'?

If no – *explain: ecological restoration is the process of recovering an ecosystem that has been degraded, damaged or destroyed.*

If yes - could you explain what the term ecological restoration means to you?

5.2 Do you think ecological restoration of the Dwars River should be a priority?

5.2.1 Why?

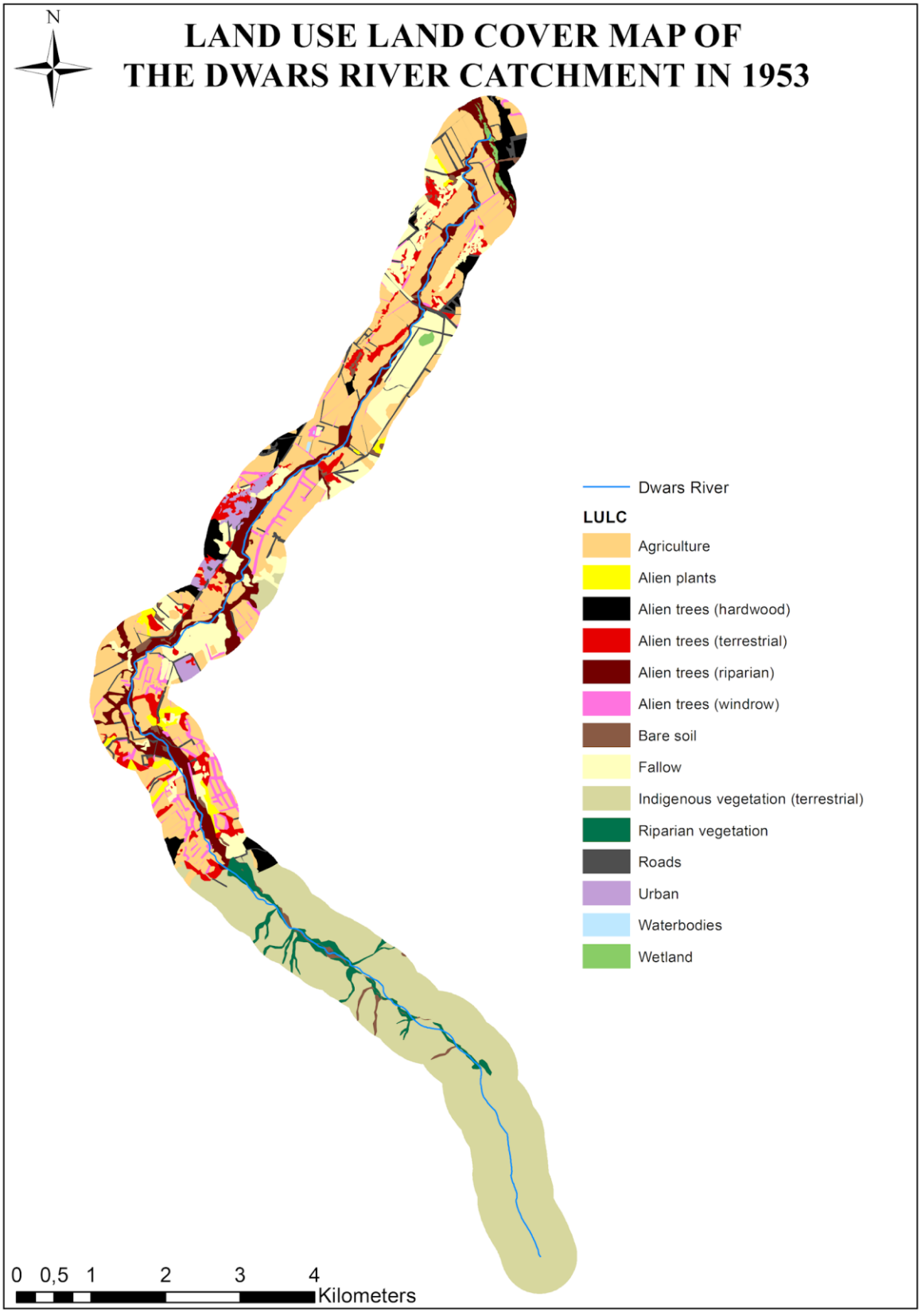
5.3 In what ways would you be willing to contribute effort to restore the Dwars River, if at all?

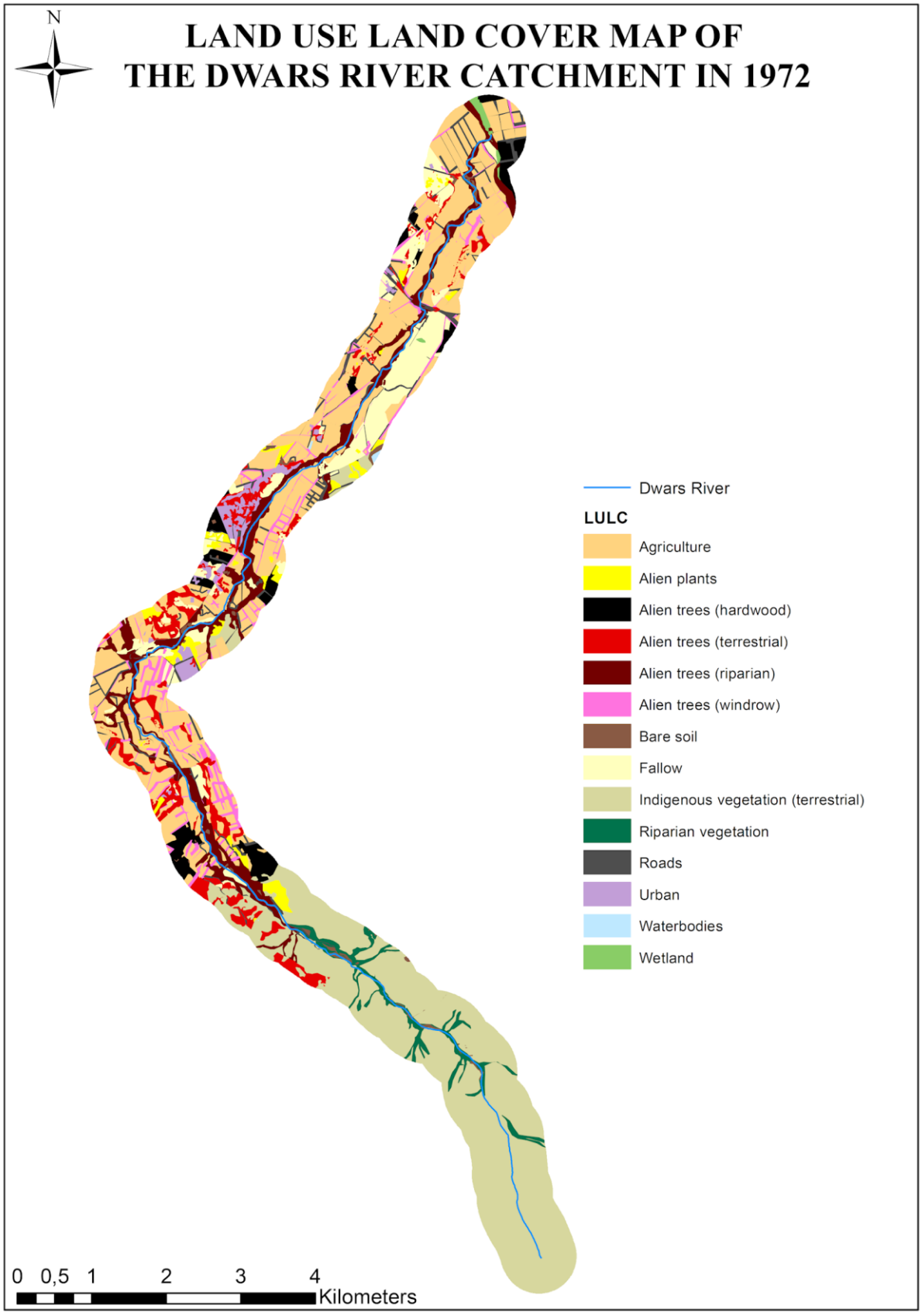
5.4 Do you utilize the Dwars River for irrigation?

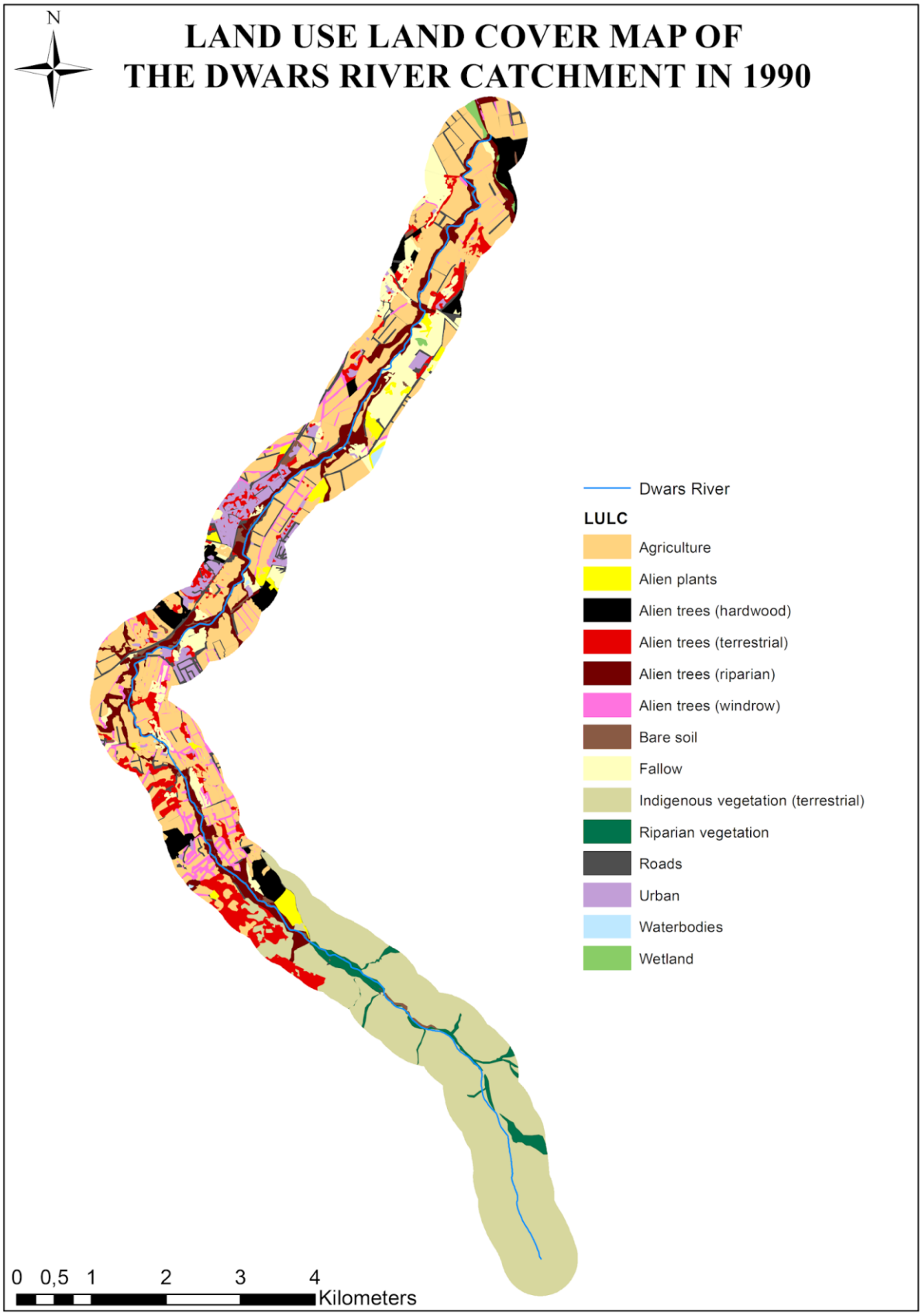
a. *If yes* -how do you extract the water from the river?

Closing Lastly, do you by any chance have any old photographs of the Dwars River or your property that you could send to us via email?

SUPPLEMENTARY MATERIAL S3 – Digitized maps




N
LAND USE LAND COVER MAP OF
THE DWARS RIVER CATCHMENT IN 1972
Dwars River
LULC
Agriculture
Alien plants
Alien trees (hardwood)
Alien trees (terrestrial)
Alien trees (riparian)
Alien trees (windrow)
Bare soil
Fallow
Indigenous vegetation (terrestrial)
Riparian vegetation
Roads
Urban
Waterbodies
Wetland
0 0,5 1 2 3 4
Kilometers


N
LAND USE LAND COVER MAP OF
THE DWARS RIVER CATCHMENT IN 1990
Dwars River
LULC
Agriculture
Alien plants
Alien trees (hardwood)
Alien trees (terrestrial)
Alien trees (riparian)
Alien trees (windrow)
Bare soil
Fallow
Indigenous vegetation (terrestrial)
Riparian vegetation
Roads
Urban
Waterbodies
Wetland
0 0,5 1 2 3 4
Kilometers

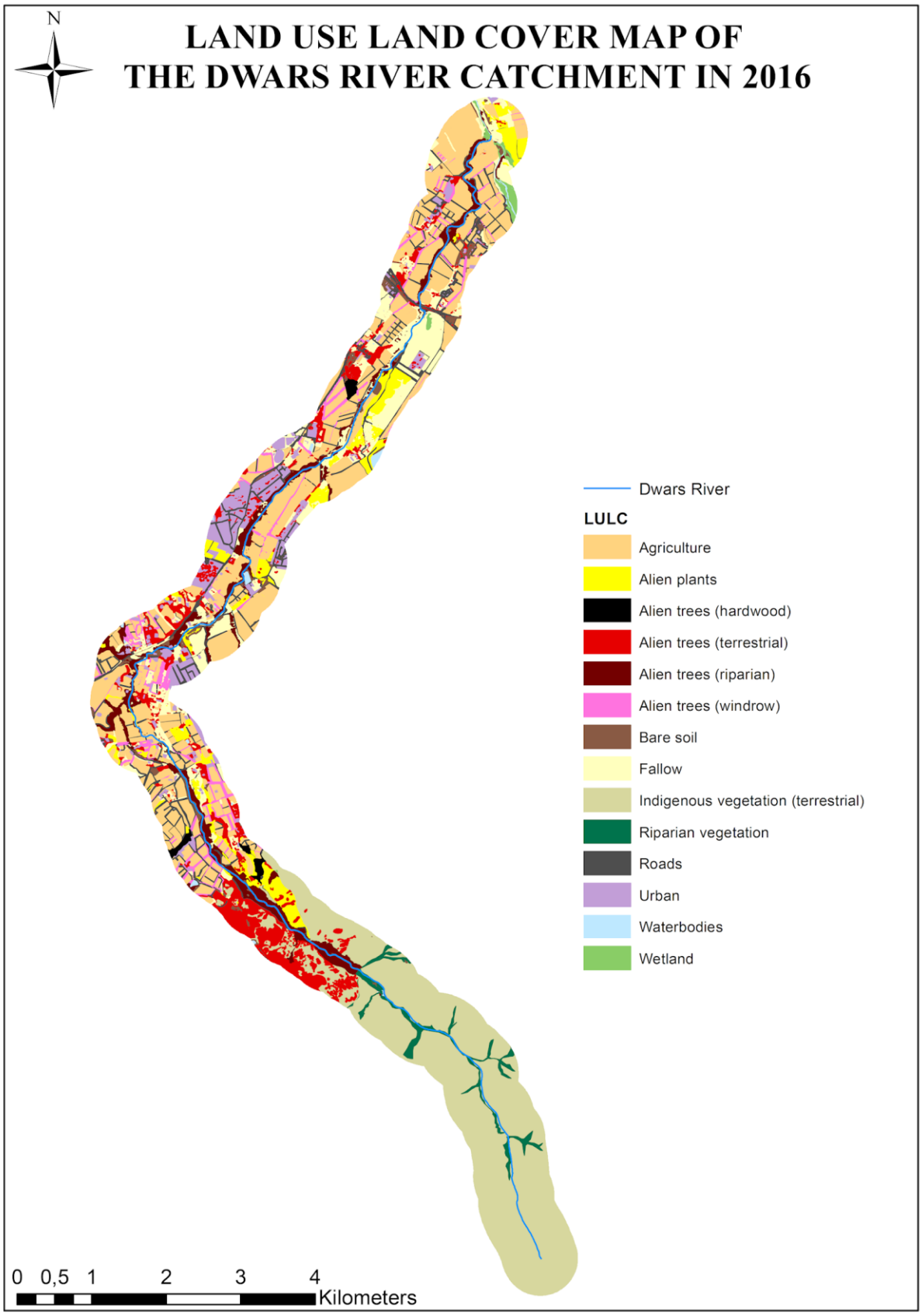

N
LAND USE LAND COVER MAP OF
THE DWARS RIVER CATCHMENT IN 2016
Dwars River
LULC
Agriculture
Alien plants
Alien trees (hardwood)
Alien trees (terrestrial)
Alien trees (riparian)
Alien trees (windrow)
Bare soil
Fallow
Indigenous vegetation (terrestrial)
Riparian vegetation
Roads
Urban
Waterbodies
Wetland
0 0,5 1 2 3 4
Kilometers

Table S10. Mann-Kendall Statistic (S) and p-values for the five classes of alien vegetation cover within the lower, middle and upper sections of the riparian zone (250 m) of the Dwars River, Western Cape

	Alien weeds	Alien trees (hardwood)	Alien trees (riparian)	Alien trees (terrestrial)	Alien trees (windbreak)
Lower (S, p)	4, 0.308	-4, 0.308	0, 1	4, 0.308	0, 1
Middle (S, p)	6, 0.089	-2, 0.730	2, 0.730	6, 0.089	0, 1
Upper (S, p)	0, N/A	0, N/A	3, 0.037	3, 0.371	0, N/A

Appendix 6: Project Dissemination Information

The South African NATWiP project team working on this WRC project and the greater JPI project is composed of Prof Karen Esler and Dr Alanna Rebelo, as well as Dandi Kritzinger, an honours student, all from the Conservation Ecology & Entomology Department, Stellenbosch University. In this section, we outline the dissemination of the project, conference attendance, publications and key project meetings and workshops.

6.1 Project dissemination

Two platforms have been set up for project-related disseminations: the project website and a social media page on facebook, and the study sites can be viewed on a map website (**Table 10**).

***Table 10**. Platforms established for project-related dissemination.*

Item	Link
The project website	http://www.natwip.solutions/
The South African case studies	http://www.natwip.solutions/Pages/safrica.html
The project Facebook page	https://www.facebook.com/NBSforwater/
The NATWiP Project maps	http://miljo.ngi.no/natwip/

6.2 Conference attendance

Due to the pandemic, there was limited opportunity to attend conferences, however the South African team still managed to participate in two conferences, one local, and one international, to disseminate NATWiP project results (**Table 11).**

***Table 11**. Participation in conferences by the South African NATWiP project team.*

Dates	Conference	South African lead	Link
23-27 August 2021	World Water Week	Alanna & Karen	https://youtu.be/HdyTFeF9Qw0
7-9 September 2021	Fynbos Forum	Karen	https://youtu.be/a0zCq54pH34

6.3 Publications

The South African NATWiP Team is involved in four scientific publications besides the other project-related outputs described in the results section (**Table 12**).

***Table 12**. Publications that the South African NATWiP project team are involved in.*

Publication	Year (status)	Title
Du Plessis, N., **Rebelo, A.J.,** Richardson, D.M. and **K.J. Esler**	2021 (accepted: *Ambio*)	Guiding long-term restoration of riparian ecosystems degraded by plant invasions in peri-urban areas: Insights from South Africa.

Lima, A.P.M., Rodrigues, A.F., Latawiec, A.E., Dib, V., Gomes, F. Maioli, V. Pena, I. Tubenclack, F., Oen, A.M.P, **Rebelo, A. J. Esler, K. J.,** Agudelo, A.R., Bosch, E.R., Singh, N. Suleiman, L. Hale, S.E.	2022 (submitted)	Framework for planning and evaluation of nature-based solutions.
Ramírez Agudelo, A, Lima, A.P.M., Rodrigues, A.F., Latawiec, A.E., Dib, V., Gomes, F. Maioli, V. Pena, I. Tubenclack, F., Oen, A.M.P, **Rebelo, A. J. Esler, K. J.,** Agudelo, A.R., Bosch, E.R., Singh, N. Suleiman, L. Hale, S.E.	2022 (in progress)	Nature-based solutions: Opening the narratives to close the water gap
Rebelo, A.J., Du Plessis, N., and **K.J. Esler**	2021 (submitted)	What are the benefits of water-related investments into nature in the peri-urban? A Global South perspective

6.4 Project meetings & workshops

The project was highly interactive and strengthened research collaborations with other institutions around the world. Project management was delegated, and each country/institution played a role in leading or co-leading a certain work package (WP). South Africa and Sweden co-coordinated WP4. Meetings and workshops were held, with regular smaller ad hoc meetings in between as needed (**Table 13**). The team was all-female and represented six different countries from around the world (Plate 1).

***Table 13**. Key NATWiP project meetings and workshops from 2020-2021.*

Dates	**Event**	**South African lead**
24-25 September 2020	NATWIP Midterm Meeting	Alanna & Karen (WP4)
17 February 2021	WRC Reference Group Meeting	Alanna & Karen
19 May 2021	NATWIP Handbook Co-design Workshop	Alanna & Karen
29-30 September 2021	NATWIP WP3 Workshop	-