Choosing Nature-based solutions

Development of a multi-criteria framework for selecting nature-based solutions in the urban context

Case study Tam Ky, Vietnam

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The cover of this report shows Tam Ky City, as viewed from a bridge across the Bàn Thạch river at the north-side of the city. I took this picture in December 2022 while visiting Tam Ky.

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By

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Abstract

Nature-Based Solutions (NBS) are increasingly gaining popularity due to their multifaceted benefits addressing various environmental and societal challenges for cities. The pursuit of achieving sustainable urban water management and enhancing resilience and well-being has expanded the range of NBS applications considered useful. Currently, traditional sustainable urban drainage practices sit alongside urban vegetation, such as parks, street trees and green facades, to address specific urban challenges, all delivering different benefits and tradeoffs. This diversity of applicable NBS introduces a decision-making challenge: Choosing appropriate nature-based solutions for cities.

To address this challenge, this thesis developed a framework to assist decision-makers in selecting a set of potential suitable nature-based solutions for urban areas. The tool combines a screening method with a multi-criteria analysis that integrates public preferences, benefits, and tradeoffs of NBS based on ecosystem service variables. The new methodology has been demonstrated in the city of Tam Ky, Vietnam. The case study results showed successful integration of public preferences, benefits, and tradeoffs of NBS based on ecosystem service variables in the selection process. Combining this data into a method to visually present rank scores allowed to holistically evaluate the performances of different NBS relative to each other. This output can aid decision-makers and planners in gaining a more holistic understanding of the importance of local ecosystem services, enabling to align potential suitable NBS with public wishes and needs, and selecting a set of potential suitable measures accordingly.

Acknowledgements

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Max de Boer

Wormer, 23-05-2023

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List of Abbreviations

Abbreviation	**Definitions**
AHP	Analytic hierarchy process
ANOVA	Analysis of variance
CV	Covariance of variation
DAT	Direct assignment technique
DONRE	Department of natural resources and environment
ES	Ecosystem service
EDS	Ecosystem dis-service
ESCF	Ecosystem service cascade framework
MCA	Multi-criteria analysis
MEA	Millennium ecosystem assessment
NBS	Nature-based solutions
PMU	Project management unit
TEEB	The Economics of Ecosystems and Biodiversity
SUDS	Sustainable urban drainage systems
WWTP	Wastewater treatment plant

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1 Introduction

The world is urbanising rapidly. Right now, over half of the world population lives in cities, and this number is expected to increase to more than 70 percent in 2050 (World Bank, 2021). Cities worldwide are struggling with the effects of climate change as it interacts with urbanization, the loss of ecosystem services, biodiversity, and increasing disparities in wealth. These urban challenges, such as heat island effects, air and water pollution, flooding, droughts, and loss of biodiversity, can impact the health and well-being of urban residents, leading to economic losses, social insecurity, and a decrease in people's quality of life (World Bank, 2021). These resilience challenges will only become more intense and frequent with climate change and increased urbanisation (Dolman & Ogunyoye, 2018).

To build climate resilience and reduce disaster risk for cities there traditionally has been a strong fucus on grey infrastructure such as dikes, dams, or pipe systems (Worldbank, 2021, Ferreira et al 2020, Huang et al., 2020). However, this grey infrastructure is often designed to be single purpose (e.g., to reduce flood risk), and designed for a specific rainfall return period. This makes grey infrastructure unable to adapt to the increasing future uncertainty regarding climate change. Also, these single purpose infrastructures do not provide additional benefits and can even induce negative consequences for the environment and urban ecosystems (Ruangpan et al., 2021; Huang et al., 2020). This makes grey infrastructure unable to adequately address the range of increasing resilience challenges in urban areas due to climate change (Worldbank, 2021). The increasing need for flexible and multifunctional solutions has in recent decades increased the interest for nature-based solutions (NBS).

The implementation of nature-based solution (NBS) is seen as an effective approach to tackle many urban challenges simultaneously (Iwaskuz et al., 2019.; Watkin et al., 2019). NBS can be defined as “solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience” (European Commission, 2016). The main advantage of NBS and reason for the rising popularity, is their capability to provide these environmental, social, and economic benefits (also called co-benefits) (Ommer et al., 2022; Huang et al., 2020; Gomez et al., 2020; Saribi et al., 2022). NBS provide this range of benefits by enhancing and delivering ecosystem services in cities (Iwaskuz et al., 2019.; Watkin et al., 2019.; Ferreira et al., 2021, Saribi et al.; 2022). Where ecosystem services are defined as the positive impacts of ecosystem functions on human health and wellbeing (MEA, 2005; TEEB, 2011; Costanza et al., 2014). For example, green roofs and street trees can help to reduce urban heat island effects by providing cooling and shade, while also improving air quality by capturing pollutants. While urban forests and parks can reduce urban noise pollution, provide recreational spaces, and enhances biodiversity. These effects in return can provide additional socioeconomic benefits, such as an increase in property prices, or an improvement in citizens health and safety (see figure 1).

This work focusses on NBS for urban areas. Therefore, the term NBS refers to any build intervention in the urban area that can address water related risk, while also providing additional benefits due to the implementation or mimicking of nature. Hence, the term functions as an umbrella term that encompasses several approaches such as Low Impact Developments (LIDs), Blue-Green Infrastructure (BGI), Sustainable Urban Drainage Systems (SUDS), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD) and Green Infrastructure (GI).

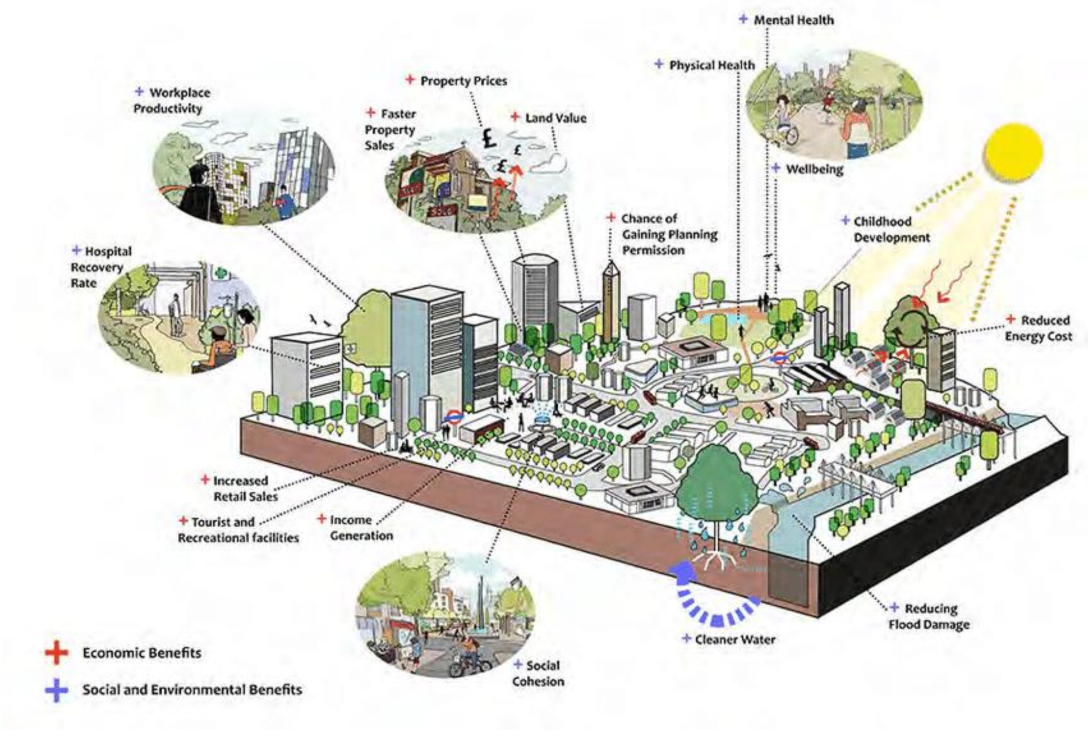


Figure 1: Example of the benefits that NBS can provide for inhabitants of cities. source: Redon, 2017

1.1 Problem statement

Selecting the most appropriate NBS for an urban area is a challenging task (Alves et al., 2018). This is because many kinds of NBS for urban areas exist, all delivering different benefits. Also, different NBS have different site-specific implementation restrictions, costs, and other restrictions based on area-specific socio-economic context. The most fitting solution will depend on these area-specific local needs and attributes (Ruangpan et al., 2020; Jia et al., 2013), where the most optimal solution is the one generating the most benefits in an area in relation to the physical resources required for implementation (Kabisch et al., 2016; Croesser et al., 2021; Uzuma et al., 2014).

It is therefore important to assess all advantages and disadvantages of the solution to make a well-defined decision about which NBS is optimal to implement in an area (Watkin et al., 2019). In order to do this, NBS valuation becomes essential (Watkin et al., 2019, Liquite et al., 2016). Where valuation refers to assigning value to the benefits of NBS either through monetization or to an estimation of importance (Liquete et al., 2016; Gómez-Baggethun et al., 2014).

Due to the large number of NBS options to select from, it is in the preliminary stage too time-consuming and unfeasible to value all measure performances in detail (i.e., quantification and monetization of all the benefits and costs using modeling). Thus, prior to a detailed evaluation of NBS by quantifying performances, it is important to first pre-select appropriate NBS for the urban area (Jia et al., 2013; Ruangpan et al., 2022). This should be done by identifying the multiple benefits and disadvantages of NBS and comparing them with alternative options (Raymond et al., 2017). To help with this pre-selection, researchers have developed decision support tools to screen, value and select NBS (Calliari et al., 2019; Alves et al., 2020). This is most often done by using MCA (Lerer et al., 2015).

Multi-criteria analysis (MCA) is a decision-making tool used to assess and rank alternatives or options based on multiple quantitative and qualitative criteria, offering a method to structure complex problems and achieving value integration (Brito & Evers, 2016; Dogson, 2009; Liquete et al., 2016). Due to the complexity of NBS covering multiple objectives on both technical and social domains, MCAs are very useful for pre-selecting nature-based solutions (Croeser et al., 2021; Ruangpan et al., 2020; Lerer et al., 2015). However, MCA tools for the selection of specific NBS considering the multiple benefits for cities remain scarce (Ruangpan et al., 2021; Croeser et al., 2021). In Chapter two all existing tools for the selection of NBS making use of MCA are reviewed. The literature review has identified the following knowledge gaps for tools applying MCA for NBS selection:

1. *Previous NBS selection tools applying MCA lack integration of local citizens involvement in the selection process of NBS.*
2. *Only a limited number of benefits have been included as criteria in NBS MCA selection tools.*
3. *Possible negative side effects induced by NBS implementation have not been previously assessed by NBS selection tools using MCA.*

To improve on these aspects a new methodology for the selection of NBS need to be adopted to demonstrate and communicate the total impact of NBS. A promising way of doing this is by adapting an ecosystem service approach to select NBS. This approach means that all benefits provided by NBS are framed and assessed in terms of ecosystem services (potential benefits due to nature) and disservices (possible negative effect due to nature) as the main tool for measure selection. Also, the implementation of the ecosystem service concept is still rather novel in the areas of urban water management and urban planning, and approaches to operationalize ecosystem services into local decision-making is still a knowledge gap (Uzuma et al., 2014; Balzan et al., 2021).

Therefore, it would be interesting to develop a new MCA tool for the selection of NBS that assesses the multiple benefits of NBS making use of the ecosystem service concept.

1.2 Objective and research questions

The main objective of this master thesis is to develop and test a new holistic MCA framework that can be used to to rank and select suitable NBS for an urban area, using the concept of ecosystem services and disservices to evaluate NBS benefits, while also incorporating public participation in the decision-making processes. This with the goal to support NBS decision making for stakeholders and increase the knowledge of both public perceptions and ecosystem service assessments related to NBS.

This objective gives rise to the main research question of this research:

How can an MCA tool be used to select suitable NBS for an urban area while integrating the ecosystem services concept and public participation in the decision-making process?

To answer the main research question, the following steps need to be taken. A literature review needs to be conducted to assess previously conducted pre-assessment MCA frameworks for the selection of nature-based solutions. This review aims to discover the similarities and differences between previous works, potential knowledge gaps, and possible improvements. This provides information on which properties and attributes should be included in the new framework during its development. Also, the concept of ecosystem services is reviewed as it plays a central role in this work. The objective here is to clarify how NBS can generate urban ecosystem services and how this impacts human well-being through the provisioning of benefits. This helps to establish connections between NBS, urban ecosystem services, and disservices and helps to identify which criteria need to be considered for the new tool.

As far aware of no comprehensive list of the performance of different NBS to deliver ecosystem services and disservices exist yet. Therefore, new methods need to be developed to provide an overview to what extent different NBS are able to supply ecosystem services and disservices. Assessing a wider range of benefits and possible negative effects provided by NBS allows policymakers, planners, and stakeholders to better recognize opportunities and trade-offs, leading to more informed decisions about NBS implementation (Raymond et al.,2017; Watkin et al., 2019; Giordano et al., 2020; Ommer et al., 2022). The development of these methods will answer the first supporting question:

To what extent are different NBS able to supply ecosystem services and disservices?

Current tools using MCA do not integrate the perceptions of the public in the selection process. Project acceptability and effectiveness in NBS projects are generally low if no opportunity of public participation in the decision process is considered (Dai et al., 2021; Shen & Wang, 2013). Increasing citizen engagement in the selection process can improve the outcome of the decision progress since it helps to select solutions that are understood and desired by citizens, increasing public support for NBS (Derkzen et al., 2017; Miller et al., 2019; Aubert et al., 2020). Hence, new methods need to be developed to incorporate public participation in the framework. This will give insight into the importance of the different criteria selected for the framework, which in return impacts the selection of measures. The development of this new tool will answer the second supporting question:

How can public perceptions of NBS benefits and disbenefits be integrated in the decision-making process, and how do these perceptions of the public impact the selection of measures?

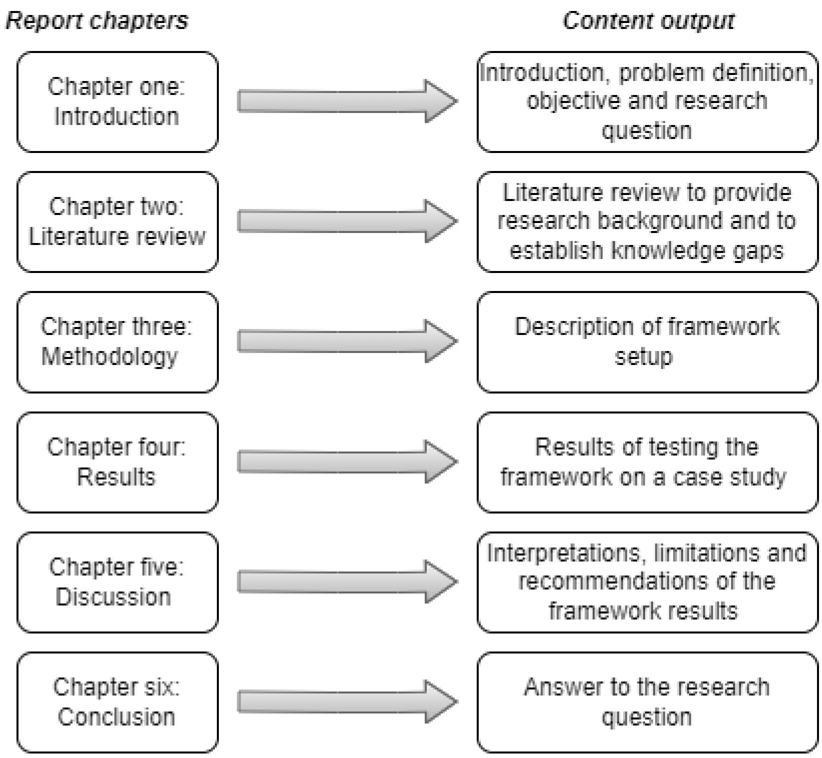


Figure 2: Report structure.

The report is divided in six chapters. The introduction is already discussed in chapter 1. The literature review can be found in Chapter 2. Chapter 3 will provide all the methods used to develop the new tool. In chapter 4 the new methodology will be tested by applying the tool on a case study area. The results of the testing of the framework will present the answers for both supporting questions. In chapter 5 the results will be interpreted, the limitations will be discussed and recommendations for further improvements of the tool, and future research will be given. In chapter 6 the main research question will be answered.

2 Literature review

This chapter exist of two separate parts. The first part discusses the concepts of the ecosystem services, and ecosystem dis-services, as they play a central role in this work. This part has the objective to provide background information and clarify how NBS can generate urban ecosystem services and how this impacts human wellbeing trough the provisioning of benefits. This helps to create links between NBS, urban ecosystem services and disservices and helps to identify which criteria need to be considered for the new tool. In the second part existing frameworks specialised for selecting specific NBS considering multiple benefits making use of MCA will be reviewed. The aim of this review is to map the general properties of previous works and to review general NBS literature to identify what knowledge gaps exist regarding NBS selection. This output provides information on which properties and attributes should be included in the new framework during its development.

2.1 Linking NBS, ecosystem (dis-)services and (dis)benefits

2.1.1 The concept of ecosystem services

Ecosystem services are the positive impacts of ecosystem functions on human health and wellbeing (Costanza et al., 2014; MEA, 2005; TEEB, 2011). The ecosystem service concept is useful because it provides a clear and usable typology that relates the functioning of ecosystems to human health and well-being (Lyytimäki and Sipilä, 2009; Gómez-Baggethun et al., 2013; Martin-Ortega et al., 2015; Bush & Doyon, 2019) (See figure 3). This link allows for a holistic framework able to assess and value ecosystems, since benefits on human health and well-being can be valued. Being multidisciplinary, the concept can also act as a boundary object, facilitating collaboration and communication between different sectors and disciplines (Bush & Doyon, 2019; Jax et al., 2013). These properties enable decision-makers to better understand the benefits that ecosystems provide to people and, consequently, how to manage natural resources in a way that supports sustainable development (Martin-Ortega et al., 2015). According to an elaborate review of urban ecosystem services by Goméz-Baggethun et al., 2013, the concept can be very important in linking cities back to the biosphere, which can help decrease the negative impact cities have on the environment, while also improving the health, resilience, and overall quality of life of the people who live there (Gómez-Baggethun et al., 2013).

A very popular and widely known classification system of ecosystem services is the one used in the frameworks of the Millennium Ecosystem Assessment (MEA, 2005) and the Economics of Ecosystems and Biodiversity (TEEB, 2011). In this classification system, all ecosystem services are grouped into four categories: regulating, provisioning, cultural, and supporting services. Regulating services are the benefits resulting from the regulation of ecosystems on the environment. For example, vegetation can improve air quality through air filtration, and wetlands can provide flood protection through water storage. Provisioning services are goods produced by ecosystems necessary for survival, such as wood, fibers, food, medicines, and a freshwater supply. Cultural services are the non-material services people obtain from being in contact with ecosystems. They include opportunities for recreation, aesthetic values and increased social cohesion. Supporting services are the underlying processes and factors necessary to produce ecosystem services, such as photosynthesis, nutrient recycling, water cycling and soil formation (Daily, 1997).

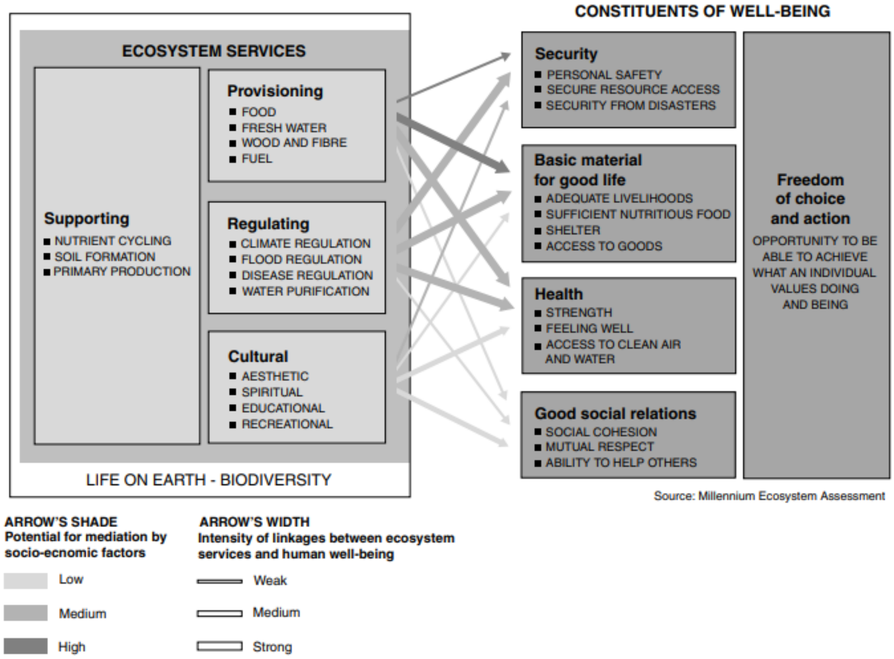


Figure 3: Examples of some ecosystem services as categorised in cultural, regulating, provisioning, and supporting services and their relation to human well-being as classified by the Millennium Ecosystem Assessment framework (MEA, 2005). *Source: Millennium Ecosystem Assessment (2005). Ecosystems and human well-being: Synthesis. Washington, DC: Island Press.*

2.1.2 The ecosystem service cascade framework

To apply the ecosystem service concept to NBS, it is important to recognize NBS as ecological infrastructure in the urban environment that can provide ecosystem services (ES) (Notte & Zulian, 2021). In other words, recognizing that NBS provide their multiple benefits through the delivery of ecosystem services (Cohen-Shacham et al., 2016; Bush & Doyon, 2019; Iwaskuz et al., 2019.; Watkin et al., 2019.; Ferreira et al., 2021, Saribi et al.; 2022). To understand the underlying relations why NBS can deliver multiple ES and benefits may best be explained by using the ecosystem service cascade model (ESCF) developed by Haines-Young & Potschin (2010) (see figure 4). This conceptual model was developed with the purpose of helping users better distinguish between ecosystem functions, ecosystem services, and the benefits that flow from these services, by specifying and visualizing the relationships between these components.

NBS are ‘nature-based’. Therefore, implementing NBS provides ecological infrastructure in the city. Ecological infrastructure are all semi-natural or completely natural structural components of ecosystems that are important in the provisioning of ecosystem services (Gómez-Baggethun et al., 2013). In the urban context, this means all the water bodies and vegetation found in the urban area, such as parks, gardens, street trees, grassland, hedges, urban forests, green roofs, wetlands, streams, ponds, lakes, and rivers (Bolund & Hunhammar 1999; Lyytimäki & Sipilä 2009; Gómez-Baggethun et al. 2013).

The underlying relations that link the multiple benefits of NBS are best explained by an example, as shown in figure 4: Ecological infrastructure (i.e., biophysical structure) is created and develops due to ecosystem service processes (supporting services in TEEB and MEA) such as net primary production or nutrient recycling. This created biophysical structure such as an urban forest has a physical effect on the environment; it causes rainwater to get intercepted by the trees and slowed and absorbed into the humus rich soil. This decreases overland runoff. This physical effect is an ecosystem function. This function has a consequence: it decreases flooding in the area. This consequence of an ecosystem function that humans find useful is called the ecosystem service. This ecosystem service, flood risk reduction, has a positive effect on human well-being, such as improvement in health or an increase in safety. These effects are the benefits on human health and well-being obtained due to flood protection. This increase in safety has a perceived value for people; for example, people want to pay a certain amount of money for this safety. This is a metric on how a benefit is valued.

These links show how NBS can provide ecosystem functions that are positive for human health and wellbeing (ecosystem services). However, these same processes can also cause ecosystem disservices (EDS). Ecosystem disservice can be divined as "ecosystem generated functions and processes that are perceived as negative for human well-being" (Lyytimäki and Sipilä 2009, Gómez-Baggethun et al. 2013, Shachleton et al., 2016). For example, harm caused by nature by facilitating suitable habitats for pests, dangerous animals, mosquitoes, and ticks, which can increase the prevalence of vector-borne diseases or animal attacks. Other examples include an increase in allergic reactions due to heightened pollen levels, or damage to infrastructure caused by the roots of street trees or vegetation on green roofs.

The ESCF can also be used to explain the mechanisms that underlie ecosystem disservices (Wu et al., 2021). For example, an NBS providing ecological infrastructure, such as street trees, develops a large root system by conducting photosynthesis (ecosystem service process). This has a physical effect; it alters the ground (ecosystem function). This effect may lead to the unintended consequence of breaking up the pavements above and sewer system below. This consequence of an ecosystem function, the damaging of infrastructure, is not beneficial for humans. This is the ecosystem disservice. This ecosystem disservice can negatively impact human health and wellbeing, such as a decrease in infrastructure service and feelings of unsafety. This in return causes a certain value loss, which is a metric on how the negative effect is valued.

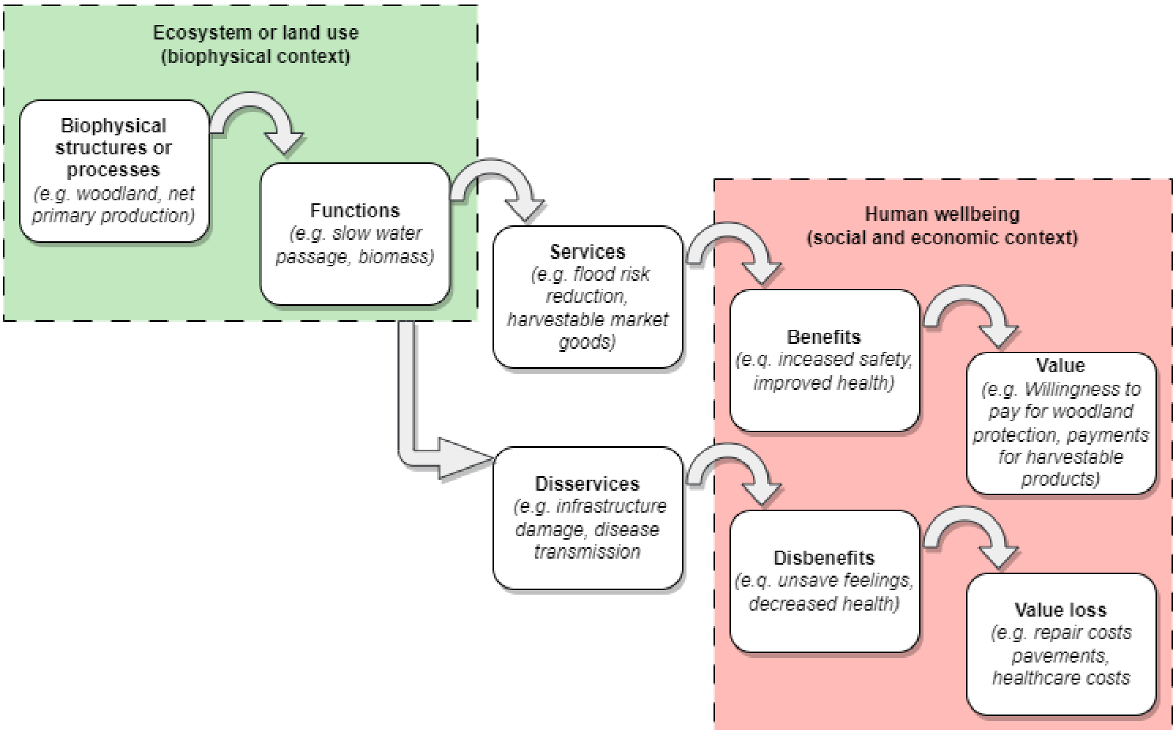


Figure 4: The ecosystem service cascade framework. By examining the flow of ecosystem services and their contributions to human well-being using the ESCF, the linkage of NBS benefits and disbeneftis can be explained. Applying this hierarchical structure of explaining the underlying processes can also help decision-makers to avoid double counting problems when valuating NBS (Haines-Young & Potschin, 2010; Zhang et al., 2022; Heink & Jax 2019). Adapted from: Haines-Young and Potschin (2010) and Wu et al. (2021).

The ESCF of Haines-Young & Potschin contradicts to the definition given by TEEB and the MA, by stating that a service is not a benefit. A service is something that changes the level of wellbeing while retaining the link to the underlying ecosystem functions, structures, and processes (Heink & Jax, 2019). Benefits that flow from ecosystem services are the things that can be valued in monetary or social terms that no longer have any direct functional connection to the original systems they came from (Fisher & Turner, 2008; Haines-Young & Potschin, 2010; Heink & Jax, 2019). This means, benefits are the valuation end points of the cascade (Heink & Jax 2019). The value of an ES is determined by the benefits it provides, as is the value of an ecosystem function determined by the value of ES (Heink & Jax 2019). Because of this, it is important to clearly distinguish between different levels of the cascade when valuing for example a potential NBS or a certain landscape. Since the mixing of multiple levels in the cascade, such as ES and benefits, can lead to double counting problems (Zhang et al., 2022, Heink & Jax 2019, Haines-Young & Potschin, 2010, Fisher & Turner, 2008). This is because benefits flow from ES, thus valuing both the ES as the benefits that arise due to the ES is double counting the value of the ES. For example, both valuing urban heat island mitigation (ES) and building energy reduction (benefit) resulting from heat island mitigation, would ''double count'' the value that green roofs add on heat reduction.

This double counting issue is the same reason why supporting services are excluded from the ECSF and considered ecosystem processes. As stated by MEA and TEEB, the supporting services are the service category that gives rise to all other services. If a supporting service such as water cycling is valuated, it will also automatically count for the provisioning, cultural, and regulating services it generates, therefore partly double counting these ES.

2.2 Multi criteria analysis frameworks for the selection of NBS

As previously stated in the problem statement, decision making for suitable NBS is a difficult task Therefore, researchers developed decision support tools with the goal to help decision-makers select suitable solutions for a given area (Calliari et al., 2019; Alves et al., 2020). The review of Lerer et al. (2015) classified this kind of decision support tool as "Which" tools, answering which measures are best suitable to implement for a given area. Tools that provide this functionality are generally web-based applications to help screen applicable solutions, such as the RECONECT measure selector tool (RECONECT, 2023), PEARL KB (PEARL, 2023), Urban blue-green grids (atelier GROENBLAUW, 2023), and Naturally Resilient Communities solutions (nrcsolutions, 2023), or more comprehensive MCA tools (Lerer et al., 2015).

MCAs generally perform better in assessing ecosystem services and therefore multifunctional NBS than traditional CBA due to its capacity to consider various aspects of well-being, in ecological, economic, and cultural dimensions (Saarikoski et al., 2016). MCAs are also able to transparently show the advantages and disadvantages of different alternatives, showing distributions of gains and losses among beneficiaries of ecosystem services (Saarikoski et al., 2016). Because of these properties, MCAs are very useful for pre-selecting nature-based solutions (Croeser et al., 2021; Ruangpan et al., 2020; Lerer et al., 2015).

In table 1, all (as far as aware of) available MCA frameworks specialized to guide NBS selection produced in the last 15 years are reviewed. From the table, differences and similarities between the decision support tools can be observed.

2.2.1 General properties

The older tools consider only a few commonly used measures such as permeable pavements and rain gardens and refer to them as SUDS (Loc et al., 2017; Alves et al., 2018), or BMPs (Martin et al., 2007; Jia et al., 2013; Yough et al., 2010; Aceves and Fuamba, 2015). These terms refer to NBS measures that explicitly address urban pluvial stormwater management. The more recently developed tools refer to the solutions as NBS (Croeser et al., 2021; Ruangpan et al., 2020) and consider a wider spectrum of options, including SUDS, natural river engineering solutions, and urban vegetation such as parks, forests, and street trees. Hence, they capture the wider concept of NBS compared to the SUDS/BMP approaches.

All tools, except the MCA tool of Loc et al. (2017) and Croesser et al. (2021) include some form of screening analysis in their work. This is important to include since not all NBS are suitable to implement at every site. Therefore, it is crucial to carry out a screening analysis to identify nature-based solutions that are compatible with local constraints (Ruangpan et al., 2020). Most authors restrict feasibility based on general site constraints, such as maximum water table depth, soil infiltration rates, slopes, bedrock depth, land use, flood type, and available space.

Also, most papers consider some cost-related criteria in their works. Since NBS decision-making often occurs within budged-constrained organizations, it's important for tools to include criteria indicating the relative costs of measures (Croesser et al., 2021). This allows to compare the costs of solutions relative to each other, helping decision making (Jia et al., 2013, Croesser et al., 2021).

2.2.2 Stakeholder participation

Multiple published papers suggest that more attention should be given to the incorporation of local stakeholders' participation and knowledge for selecting and assessing NBS (Alves et al., 2019; Ruangpan et al., 2020; Ferreira et al., 2020; Giordano et al., 2020; Croesser et al., 2021; O'Donnell et al., 2021). Involving local stakeholders in the selection of NBS can generate relevant local data and considerations that might otherwise go unnoticed or disregarded by engineers, and it can help in selecting infrastructure that is understood and desired by decision-makers (O'Donnell et al., 2021; Lupp et al., 2021; Croesser et al., 2021). Reviewed tools respond to this by allowing local decision-makers (e.g., municipalities) to weight the importance of considered criteria using different ratio assignment techniques, such as ELECTRE III (Martin et al., 2007; Aceves and Fuamba, 2015), AHP (Yough et al., 2010), or direct assignment rating (Ruangpan et al., 2021; Sarabi et al., 2022; Ariza et al., 2019). Others let stakeholders select predefined weights (Jia et al., 2013; Croesser et al., 2021; Alves et al., 2018).

As shown, efforts have been made in incorporating stakeholder participation in NBS selection process. Nevertheless, previous conducted works only considers local decision-makers in their works and disregard input from the public. Only the work of Aceves and Fuamba (2015) integrates citizens as stakeholders in the decision-making tool. Nevertheless, due to resource limitations, no formal and complete sampling method could be developed, and response levels were poor (Aceves and Fuamba, 2015). It has been found that project acceptability and effectiveness in NBS projects are generally low if no opportunity of public participation in the decision process is considered (Dai et al., 2021; Shen & Wang, 2013). Incorporating public participation in the NBS decision process enables governments to better understand public demands regarding local environmental or social priorities and concerns (Shen & Wang, 2013; Aubert et al., 2020). This, in return, increases the capability of governmental organisations in providing public services by addressing societal issues and increases citizens' awareness and knowledge about NBS (Shen & Wang, 2013; Derkzen et al., 2017). Increasing citizen engagement can improve the outcome of the decision progress since it helps to select solutions that are understood and desired by citizens, which can increase public support for NBS (Derkzen et al., 2017; Miller et al., 2019; Aubert et al., 2020).

2.2.3 Benefits assessed and double counting issues

As previously stated, the main selling point of NBS is their multifunctionality to address multiple urban resilience challenges through the delivery of multiple ecosystem service benefits. Therefore, emphasizing on the provisioning of multiple benefits provided by measures besides flood risk reduction is a very important aspect to increase the acceptance and willingness to implement NBS over traditional grey infrastructure (Alves et al, 2018; Kabisch et al., 2017). Moreover, a focus on the multifunctionality of NBS to provide multiple ES simultaneously, creates more local value and increases public support for NBS compared to approaches with a primarily focus on stormwater management (Miller et al., 2019). Assessing a wide range of benefits provided by NBS allows policymakers, planners, and stakeholders to better recognize opportunities and tradeoffs, leading to more informed decisions about NBS implementation (Raymond et al.,2017; Watkin et al., 2019; Giordano et al., 2020).

However, previously conducted NBS pre-assessment frameworks only consider a few possible additional benefits/ES. From the table can be observed that the majority of works only consider a limited number of ecosystem services and secondary benefits, focusing primarily on flood risk reduction. Especially the older frameworks (Martin et al., 2007; Yough et al., 2010; Jia et al., 2013; Aceves & Fuamba, 2015; Loc et al., 2017) incorporate a small number of benefits. This is possibly because they implement a more traditional engineering approach for the selection of criteria. These tools mainly assess aesthetics and water quality improvements besides flood risk reduction. Nevertheless, the work of Alves et al. (2019) considers a very complete and elaborate array of possible benefits but does not weight the importance of those individual benefits in the MCA. The work of Ruangpan et al. (2021) assesses 19 subgoals reflecting NBS benefits, mainly concerning biodiversity and socio-cultural related criteria. A problem arising there is that the performance scores between these subgoals are often not mutually independent, resulting in double counting issues, which is not allowed in MCA.

In the past, many assessments of the added value of benefits from NBS have been criticized for double counting (CIRIA, 2013). This criticism also seems to apply to previously conducted NBS MCA selection frameworks. For example, one criterion used in previous MCA assessment frameworks is the benefit of NBS to improve public health (Alves et al., 2018; Croesser et al., 2021; Ruangpan et al., 2021). However, health improvement is not a direct effect of NBS implementation but an aggregate benefit resulting from numerous improvements in local ecosystem service delivery, such as flood risk reduction, improved air quality, noise attenuation, recreational opportunities, and improved water quality (Doeffinger & Rubinyi, 2023). This makes the improvement of health of citizens dependent on the performance of multiple ecosystem services NBS can provide (as shown in the cascade model). Evaluating them both as criteria in MCA is therefore double counting the same aspects of value. This is not allowed in MCA, as the double-counted aspect of value would receive a higher weight in the MCA than it deserves (Dodgeson, 2009). Therefore, it is useful to clearly delineate between ecosystem services and the benefits they generate to avoid double-counting issues (Zhang et al., 2022; Heink & Jax, 2019; Haines-Young & Potschin, 2010; Fisher & Turner, 2008). This delineation has not been previously done in tools selecting NBS based on total benefits provided.

2.2.4 Ecosystem disservices / negative trade-offs

While the concept of ecosystem services is widely used in literature, ecosystem disservices (EDS) are often neglected or even completely ignored in frameworks that work with the concept of ecosystem services, and remain largely understudied (Ommer et al., 2022; Lyytimäki and Sipilä, 2009; Gómez-Baggethun et al., 2013; Shackleton et al., 2016; Wu et al., 2021; Dohren and Haase, 2015). The unbalanced framing of the functions of ecosystems as benefits only makes the concept of ecosystem services an imbalanced one (Lyytimäki and Sipilä, 2009). Ecosystem services refer only to the positive aspects produced by ecosystems and biodiversity while ignoring the negative aspects that ecosystems can have on human well-being. This lack of attention and unbalanced framing of nature may seriously hamper urban green and environmental management (Lyytimäki and Sipilä, 2009). Moreover, also assessing ecosystem disservices is especially important for study areas located in the global south, because there can be a greater diversity of disbenefits due to higher biodiversity and temperatures (Sitas et al., 2021).

This ignoring of the negative is no different from previously conducted NBS selection frameworks. From previously developed NBS selection tools, only the work of Young et al. (2010) assesses one criterion considering negative safety trade-offs, such as drowning in water bodies or other accidents due to the implementation of new measures. Ommer et al. (2022) showed in their literature review on general NBS assessment literature that available frameworks largely neglect potential disservices and primarily focus on the pre-assessment of benefits provided by NBS. They concluded that additional studies are needed on the pre-assessment of the disservices that can be caused by NBS.

2.2.5 Case study area’s

In general, studies tend to prioritize large cities and neglect middle and small-sized cities and towns (Cassiano Flores et al., 2021; Ozerol et al., 2020). Furthermore, assessment tools and frameworks for NBS often address the needs and characteristics of large cities, with comparatively less focus given to small or medium-sized cities (Cassiano Flores et al., 2021; Ozerol et al., 2020). Medium and small-sized cities also have different characteristics than large cities that can make the outcome of the selection and implementation of NBS different.

Compared to large cities, medium and small-sized cities are less densely populated than metropolitan areas (Vo, 2011), thus creating more room for NBS. Additionally, medium-sized cities have a smaller geographic scale, lower budgets to make investments for climate change adaptation, fewer human resources, and less expertise to create strategies and solutions to deal with climate change adaptation, and less autonomy than big cities (Dolman et al., 2018; Ozerol et al., 2020). Because of these factors, less local data and advanced resources might be available in mid-sized cities. Therefore, it might be more challenging for decision-makers of small to mid-sized cities to assess and select appropriate NBS compared to those of large cities.

These aspects increase the use case and applicability for user-friendly and easy-to-apply pre-assessment NBS selection tools for decision-makers of small and mid-sized cities. While previously reviewed works have focused on leading cities, small and mid-sized cities have also been used as case study areas (Ayutthaya, Marbella, and Blacksburg) with success. Testing the framework in these conditions ensures that the framework functions without requiring much data or other external resources. Ensuring the tool can be applied to most cities worldwide.

2.3 Chapter summary

The first part introduces the concept of ES, EDS and introduced the ESCF. This conceptual model provides a lens to help explain the underlying relations between ecological infrastructure NBS can generate, ecosystem services, and the benefits that flow from them. This model argues why it is important for tools that asses NBS to either consider the ES directly derived from NBS or the benefits that result from them, but not value them simultaneously. Since this would lead to double counting the same effect of origin.

By reviewing previously conducted pre-assessment MCA frameworks for the selection of NBS in the second part of this chapter, certain knowledge gaps and similarities have been identified. Here, the main knowledge gaps are summarized. Firstly, previous pre-assessment MCA frameworks have not adequately integrated local citizens' involvement in the selection process of NBS, which is an area requiring improvement. Secondly, only a limited number of benefits have been considered as criteria in previous frameworks, and some suffer from double counting issues. Lastly, the potential adverse effects resulting from NBS implementation have not yet been assessed in previous MCA frameworks.

Table 1: Available pre-assesment MCA frameworks for the selection of NBS. x mark indicates condidered criteria in the frameworks.

Available pre-assesment MCA frameworks for NBS selection	Functionalities							criteria considered															
								Ecosystem services benefits												Ecosystem disservices /negative tradeoffs	Secondairy benefits	Cost criteria	Other critera
	MCA method	Spatial scale and area of analysis	Site suitability assesment	Measures considered	Case study area (frameworks test site)	stakeholder derived weights	Citizens derived weights	Flood risk reduction	Water quality improvement	Air quality improvement	(Urban) temperature regulation	Habitat for biodiversity	Recreation and aminity	Social cohesion	Education	Aestetics	Fresh water supply (capture and reuse)	Production of market goods	Other ecosystem services				
Martin et al., 2007	ELECTRE III	National scale	x	8 SUDS	France	yes	no	x	x				x			x						x	Contribution to sustainable development
Young et al., 2010	AHP	Urban, city scale	x	12 SUDS	Blacksburg, US	yes	no	x	x							x				Safety and nuicance liability		x	
Jia et al., 2013	Liniear additive	Building scale, China	x	12 SUDS	Foshan campus, China	no	no	x	x			x				x	x					x	
Aceves and Fuamba, 2015	ELECTRE III	Neighbourhood scale	x	4 SUDS	Montreal, US	yes	yes	x	x							x						x	Measure acceptence, Contribution to sustainable development
Loc et al., 2017	AHP	City scale		4 SUDS	Ho Chi Min, Vietnam	no	no	x	x							x							
Alves et al., 2018	Liniear additive	Urban, city scale	x	28 SUDS and grey infrastructures	Marbella, Spain. Ayutthaya, Thailand	partly	no	x	x	x	x	x	x	x	x	x	x	x			Energy savings, health and wellbeing	x	
Ruangpan et al., 2020	Liniear additive	catchment scale	x	18 River management NBS	Tamnava and Nangang river basins	yes	no	x	x			x	x	x	x	x			Habitat structure		Health and welbeing impacts, increase economic benefits, job creation		Land use change, accesability, reduce disturbance ecosystems
Croesser et al., 2021	Liniear additive	Urban, city scale		40 Urban NBS (SUDS and urban green)	Liverpool, Medellin, Mantova, Quy Nhon, Valladolid,	no	no	x		x	x	x									Improve public health and wellbeing, support urban renewal		9 policy requirement criteria

3 Methodology for selecting measures

In this chapter, the methods and decisions made to develop the framework, will be explained. Additionally, the individual methodological framework steps that the decision-maker need to follow to select potential NBS will be explained. The literature review provided guidance on the properties that the framework should embody to be used as an NBS selection tool, improve upon previous works, and help address knowledge gaps. The combination of the literature review's findings and the general linear additive MCA methodology shapes the structure, properties, and components of the current NBS selection framework.

3.1 Framework structure and overview

The framework consists of two parts. The first part is a screening framework that provides a list of applicable measures for the case study area, based on flood type and local site characteristics. The methodology used for the screening framework is inspired by the works of Alves et al. (2018) and Ruangpan et al. (2021).

The second part is a linear additive MCA framework used to rank the most suitable solutions for the area. Therefore, the steps and methods in this framework are largely based on the same methodological steps taken when using this type of MCA model. This model assumes that the overall value of an option is the sum of its performance on each criterion, multiplied by a weight that reflects the relative importance of each criterion (Dodgson, 2009). Linear additive models are widely used in the literature and have a strong history of providing effective and reliable assistance to decision-makers due to their straightforwardness, ease of use, and transparency (Dodgson, 2009). Additionally, linear additive models can compare many different options across a wide range of criteria, something that other models, such as AHP, are less suitable for due to the usage of pairwise comparisons (Dodgson et al., 2009). Due to these properties, it was thought that this type of model would be very suitable for a pre-assessment framework that incorporates 19 criteria and a participatory weighting process.

The framework was developed with a focus on ease of use, so that it can be used by local decision-makers (municipalities) as a pre-assessment tool for the selection of suitable NBS for their city, without relying on external data sources, software, or expertise. This should also make the framework applicable in developing countries and remote smaller cities, where limitations in data and resources exist (Brito & Evers, 2016).

The framework steps that the user needs to follow to obtain a ranking of NBS are shown in Figure 5. In the next sections, the detailed methods and rationales for all framework steps are described.

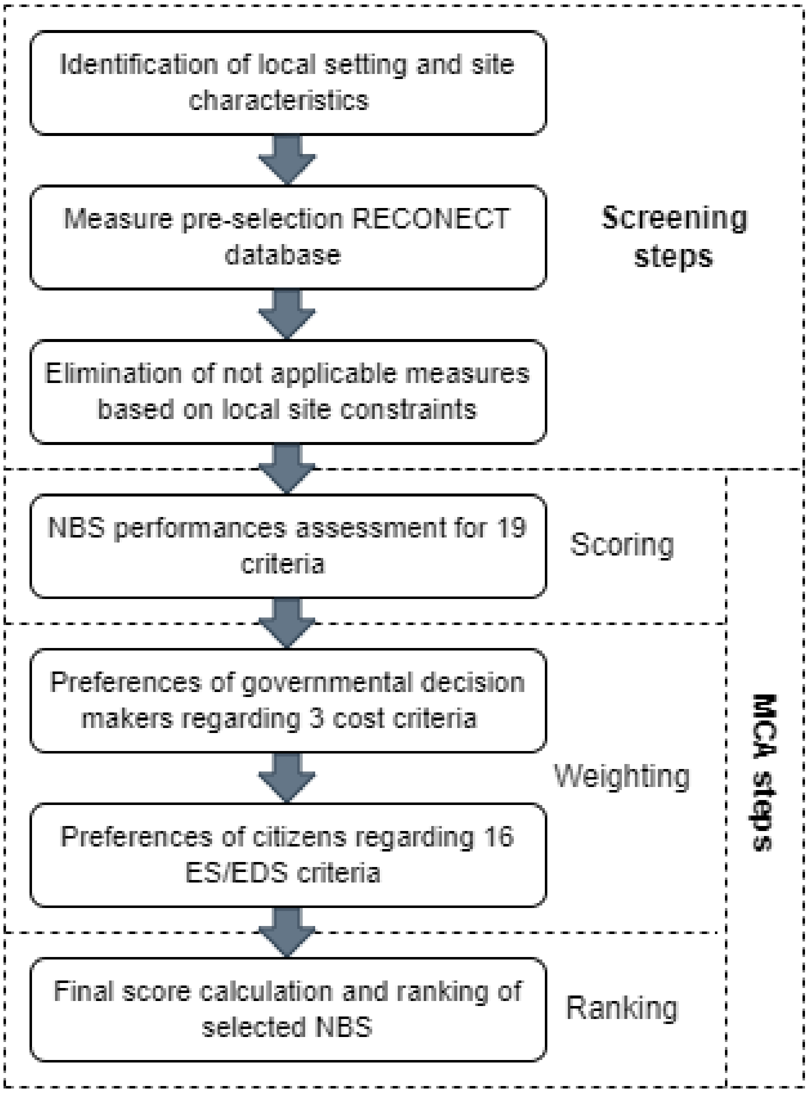


Figure 5: Framework overview. The framework consists of two parts, a screening part and an MCA part that addresses the scoring, weighting, and ranking of NBS.

3.2 Screening solutions

The first part of this framework focuses on screening out measures that are not applicable. Screening out non-applicable measures before conducting the MCA is important to exclude measures from the ranking that are not applicable in the area. The screening phase consists of three steps.

3.2.1 Identify local setting and site characteristics

The first step in this framework is to identify the local setting and site characteristics of the case study area. The identification of the local setting helps clarify the case study's context, spatial boundaries, and overarching societal problems, such as flood types and environmental issues specific to the case study area. This step assists the user in determining whether there is a genuine need to implement multifunctional NBS or not. This process can be undertaken either internally by the planning team of the municipality or externally by hired consultants by planning a meeting or workshop. Identifying the flood types present in the area is crucial for the screening process, as certain measures are not effective in reducing a particular type of flood. Additionally, identifying environmental problems and other societal challenges beyond flooding is important to assess whether there is a need for NBS that can address multiple societal challenges. By clarifying the boundaries of the case study area, it becomes possible to identify which inhabitants should receive the citizens questionnaire later in the weighting process. It also clarifies the relevant land surface types for implementation and spatial configuration, thereby determining if the site is suitable for larger-scale NBS.

The identification of local characteristics is important because it provides the necessary data input for the screening of measures, as certain measures are only applicable under specific conditions. The data required for the screening of measures is listed in Table 2. This data can be obtained by consulting local databases maintained by the municipality in which the study area is situated. However, if these datasets are not available, data on local site characteristics can be acquired through a field visit. Another approach is to gather data through conducting semi-structured interviews with local experts. If the user of the NBS selection framework is the local governmental body itself, this information can be obtained through internal communication or by scheduling meetings with other departments. The output of this step should be a comprehensive description of the study area.

Table 2: Screening data and possible methods to acquire this data needed for the screening framework.

Screening criteria	Method
Drainage slope (%)	DEM, visual inspection, local databases
Water table depth (m)	Interviews, visual inspection, local databases
Hydrologic soil class (table 3)	Interviews, visual inspection, local databases
Land surface types relevant for implementation	Interviews, visual inspection, local databases
Hazard type(s)	Interviews, local databases

Code	Soil type	Characteristics
A	Sandy clay, loamy sand, sandy loam	Soils have low runoff coefficient and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sands or gravels
B	Silty loam, loam	Soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well-drained soils with moderately fine to moderately coarse textures
C	Sandy clay loam	Soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture
D	Clay loam, sandy clay, silty clay, clay	Soils have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material

Table 3: Soil classification based on hydrologic soil groups. source: John. (1986). TN1315 - USDA (U.S. Department of Agriculture), 1986, Urban Hydrology for Small Watersheds, Technical Release 55, Natural Resources Conservation Service, Washington, D.C.

3.2.2 Provide database measures: Pre-screening database RECONECT

After obtaining knowledge about the basic site characteristics and study area context, the next step is to preselect a list of suitable NBS. This preselection is done using the RECONECT NBS Selector tool developed by IHE Delft. The RECONECT project is a large international EU-funded initiative that aims to develop a holistic framework supporting co-creation and collaboration on NBS projects (RECONECT, 2023). The NBS Selector tool is based on the six pre-selection criteria utilized in the work of Ruangpan et al. (2021) and is supported by a comprehensive database encompassing commonly employed NBS for hydro-meteorological risk reduction.

This tool was chosen because, as far as known, the RECONECT database is the only publicly available NBS catalogue specifically focused on hydrometeorological risk reduction. Conducting this step ensures that no potential applications are overlooked at the beginning of the process. Additionally, the pre-filtered database of solutions offered by the tool provides a convenient and user-friendly starting point for the selection process, saving time and effort for the user.

The NBS Selector tool employs the following filters to make a selection: measure type, hazard type, affected area, potential location, project type, and land use type (See Table 4). To be able to utilize these filters, it is important that all project properties are identified as discussed in the previous step: "Identify local setting and site characteristics."

Table 4: Filters and options used in the RECONECT measure selector tool. *Adapted from: http://www.reconect.eu/services-platform/measure-selector-tool*

Filters	Options
Type of measure	NBS Grey infrastructure
Hazard type	Pluvial flooding Fluvial flooding Flash flooding Storm surges / Coastal flooding Groundwater flooding Land slides Droughts
The affected area	Urban area Non-urban area
Potential location for measures	Urban area Coastal zone Mountainous River basin
Project type	New measures Improving existing measures
Land surface type relevant for implementation	Artificial surfaces Agricultural land Forest and semi-natural areas Wetlands Water bodies

3.2.3 Screen data base on local site characteristics and boundary conditions

The last step of the screening framework involves eliminating not applicable measures from the preselected list based on site-specific restrictions and spatial requirements of the solutions. Some infiltration-based solutions, for example, require a minimum water table depth or soil infiltration capacity to function properly or may not be feasible if the drainage area slope is too steep. Additionally, certain solutions may require a minimum spatial configuration for implementation. Boundary conditions for the implementation of all pre-selected measures were listed by conducting literature research on site implementation restrictions of SUDS and green infrastructure reported in manuals and relevant papers (Jia et al., 2013; Woods-Ballard, 2015; Ariza et al. 2019; Li et al., 2020; World bank, 2020; Saribi et al., 2022).

3.3 MCA phase

The second part of this framework is a linear additive MCA to rank the most suitable solutions for the area. First, appropriate criteria are selected to evaluate the NBS. Second, these selected criteria are scored to assess the performances of all criteria on the options. Third, weights to the criteria are assigned to indicate their relative importance or priority. Next, the scores and weights are multiplied to create a final ranking of options. At last, a sensitivity analysis is conducted to examine the robustness of the results.

3.3.1 Criteria used in the MCA framework

Criteria are the measures of performance by which the different NBS options will be evaluated. To assess the impacts of implementing NBS, it is essential to establish criteria within the MCA that cover all the impacts that NBS provide (Boruff et al., 2005; Ruangpan et al., 2021).

To be able to assess a wider range of benefits provided by NBS, reduce double counting issues, and provide a clear typology and multidisciplinary understandable framework of the benefits of NBS, the criteria selected to evaluate the performance of the considered NBS are grouped in terms of ecosystem services (ES), ecosystem disservices (EDS), and cost criteria. Additionally, incorporating EDS and costs in the framework provides a more comprehensive understanding of the impacts and trade-offs associated with these solutions, which might help decision-makers make more informed choices (Ommer et al., 2022). In total, 19 criteria are considered: 11 ecosystem services, 5 ecosystem disservices, and 3 cost criteria.

The selection and assessment of NBS are focused on the urban environment. Thus, the criteria used were selected based on ecosystem services and disservices that are important for urban ecosystems. In this context, urban ecosystems encompass all the ecological infrastructure within the city. The significant ecosystem services (ES) and ecosystem disservices (EDS) for urban environments were identified and classified using the urban ecosystem service classification and categorization provided by Gómez-Baggethun et al. (2013) and the state-of-the-art literature review of urban ecosystem disservices conducted by Dohran & Haase (2015). The ecosystem services and ecosystem disservices were classified into the following criteria groups: provisioning, cultural, habitat, and regulating services.

The identified urban ecosystem services and disservices were further modified to align with the conditions of the ESCF, which require that all services should directly impact human well-being. This exclusion involves removing supporting services, intermediate services such as pollination, and benefits that result from ecosystem services to avoid double counting.

The cost criteria considered are land acquisition, operation and maintenance costs, and construction costs. These cost criteria were selected as they represent all major aspects of costs related to NBS implementation and are often categorised in existing literature describing NBS cost categories in this way (CIRIA, 2013; Jia et al., 2013; Woods-Ballard et al., 2015; NWRM, 2015). The cost criteria are viewed in this framework as negative attributes, just like the EDS, since they can be seen as a form of disservice, just as vice versa disservices can be seen as a form of cost.

The criteria in this framework do not have a hierarchical structure because the groups in which the criteria are organized are not scored and weighted. Only the individual criteria themselves are scored and weighted. The reason for not scoring and weighting the criteria groups, is that they do not possess a clear typology like the criteria, which is essential for assigning meaningful performance values during the scoring and weighting process in MCA. Figure 6 on the following page displays all the considered criteria and the corresponding groups to which they belong. Table 5, 6, and 7 provide the definitions of the criteria and their relation to NBS.

For the selection of criteria in MCA, it is crucial that all criteria are operational, meaning they can be objectively assessed on their performance (Dodgson, 2009). The use of objective, measurable, and verifiable criteria helps reduce subjectivity in the analysis, enhancing its reliability. Therefore, the selection of ecosystem services (ES) and ecosystem disservices (EDS) was further refined based on whether they can be meaningfully measured. To support this, the last column of Table 5, 6, and 7 provides examples of performance indicators or proxies that can be used to quantify the criteria for NBS. The corresponding literature references are included to offer evidence of the indicator or proxy quantification. This information also offers guidance and a starting point for decision-makers who wish to quantify a particular ES or EDS through i.e., modeling for a selected NBS further in the decision making and implementation progress.

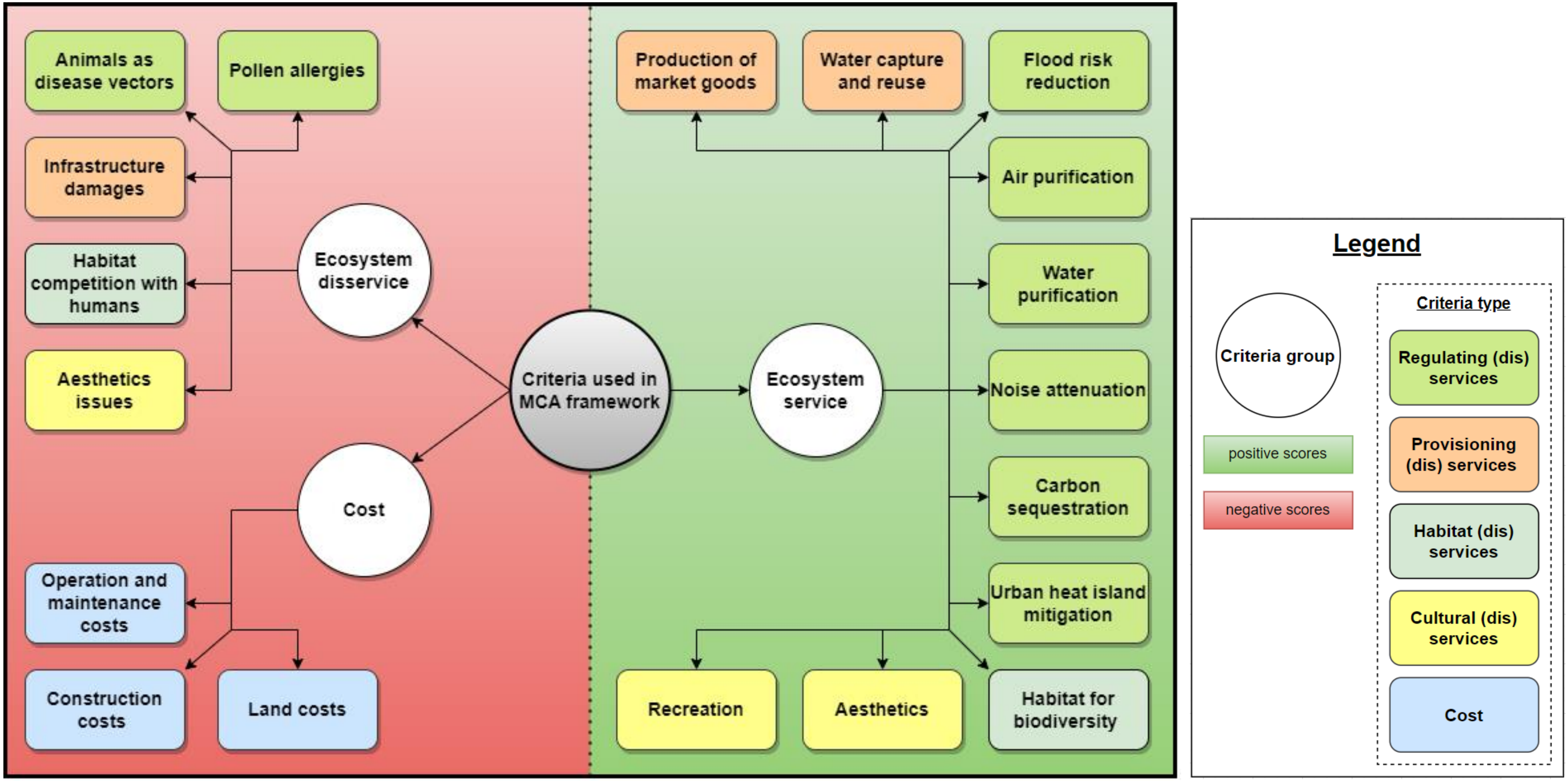


Figure 6: Selected criteria used for the framework. The criteria are grouped in terms of ES, EDS, and cost. The criteria in the red box have negative scores, as they can be seen as negative attributes considering the NBS. The criteria in the green box have positive scores, as they can be seen as the positive effects provided by NBS. The colors of the criteria indicate the criteria type, categorized in terms of service typology as adapted from the urban ES classification framework of Gómez-Baggethun et al. (2013).

Ecosystem services	Service description with link to NBS	Examples of performance indicators / proxies to quantify ES
Water purification	Storm water flowing over urban surfaces mobilizes pollutants, creating effluents with high levels of heavy metals, chemicals, (plastic) waste, excrements, and nutrients. This leads to the pollution of surface waters. Some components of nature-based solutions can improve the water quality from urban runoff by settling and retaining solids, filtering out and absorbing pollutants (Woods Ballard et al., 2015), and breaking down pollutants through biodegradation (TEEB, 2011).	Dissolved organic carbon (Liquite et al., 2016) Nitrogen load (Liquite et al., 2016) TDS (ppm) (Watkin et al. 2017) TSS (ppm) (Bastien, 2014) Turbidity (NTU) (Watkin et al. 2017) Heavy metal concentrations (Lopez et al., 2020)
Air purification	Exhaust gases from traffic or industrial activities create air pollution, which lead to problems for human health, increasing respiratory and cardiovascular diseases. Vegetation can remove air pollutants out of the atmosphere such as fine dust particles (<PM10), carbon monoxide (CO), sulphur dioxide (SO_2), ozone (O_3), and nitrogen dioxide (NO_2), improving the air quality in the area (Gómez-Baggethun et al. 2013).	Vegetation PM10 capture capacity (g PM10/m_2/year) (Tallis et al., 2010), Vegetation O_3 capture capacity (g O_3/m_2/year) (Manes et al., 2016)
Carbon sequestration	Urban vegetation, especially urban trees, function as a carbon sink by storing carbon as biomass. Also, urban soils such as in parks and lawns can act as major carbon sinks, highly surpassing the amount of carbon stored per m^2/year than in agricultural fields, coniferous forests, and native grasslands (Ariluoma, 2021). Water bodies sequester carbon through the accumulation of organic matter in sediment (Moore and Hunt, 2013). Carbon storage reduces the annual CO_2 output of a city, thus reducing the carbon footprint of the city which helps mitigating climate change.	Ecosystem carbon sequestration rates (kg C /m_2/ year), (Moore and Hunt, 2013)
Urban heat island mitigation	Urban vegetation can decrease the urban heat island effect by reflecting heat, evaporative cooling and by providing shade, decreasing ambient temperatures and temperatures in buidlings (Norton et al., 2015). Due to lower temperatures also the energy demand and thus costs of airconditionings in buildings can decrease (Ommer et al. 2022).	Cooling index (Marando et al., 2022) Shade area (Derkze et al., 2015) Evapotranspiration rates (Lovewell & Tayor, 2013) Thermal Comfort index (Zölch et al., 2019)
Noise attenuation	Due to traffic and other human activities cities can be very noisy. This can increase stress and decrease sleep quality of inhabitants, negatively affecting human health. Urban vegetation and soils can reflect, absorb, and refract sound waves, attenuating local noise from traffic and other human activities in the area (Fang & Ling, 2003).	Vegetation noise attenuation rates (dBA/m_{veg}) (Derkze et al., 2015, Fang & Ling, 2003)
Flood risk reduction	Flooding of the urban area can result in a loss of human life, property damage and hampers social-economic growth. NBS reduces the risk of flooding in the area by decreasing runoff and delaying peak flow. NBS accomplish this by increasing water storage capacity, reducing impervious surfaces to enhance infiltration rates, and promoting vegetation growth, which improves interception and evaporation rates.	Storage capacity (m_3) Land surface type runoff coefficients (L/m_2) (Tratalos et al., 2007, Fisher et al., 2010) Hydrological response time (Gericke & Smithers, 2014) Canopy interception rates (Zhang et al., 2022)

Aesthetics	Water bodies, vegetation and animals provide beautiful and natural areas where people feel comfortable. They create a sense of space and perspective around the buildings (WHO, 2016). Improving the visual aesthetic quality of a landscape due to the implementation of new water bodies and urban vegetation can help improve physical and mental health (WHO, 2016), reduce stress (Wang et al., 2019) and increase property prices (Gómez-Baggethun et al. 2013).	Landscape visual preference rating (Wang et al., 2016 Mahdieh et al., 2011 Pazhouhanfar & Mustafa, 2014)
Recreation	Green spaces, parks and water bodies allow for recreation. The recreational features of urban ecosystems are widely regarded as one of the most valued ecosystem services in cities (Bolung &Hunhammar, 1999). The recreational aspects of green and natural areas have been shown promote physical activities, reduce stress, improve mental health, and increase the number of tourists in the area (WHO, 2016).	Number of visitors (Liquite et al., 2016) Frequency of visits (Liquite et al., 2016, Schragner et al., 2016) Physical ease / accessibility index (Moore & Hunt 2012, Parrachini et al., 2014, Derkze et al., 2015) Urban green space m_2 per capita (Derkze et al., 2015, Bertram & Rehdanz, 2015) Recreation potential index (Parrachini et al., 2014)
Production of market goods	Green roofs, backyards, community gardens, green spaces, ponds, and farm fields within and around urban area's provide opportunities food production (Gómez-Baggethun et al. 2013). Local urban food production can improve the food security in an area, reduces costs and ensures freshness of goods due to short supply chains (Siegner et al., 2018; Payan et al., 2022). Urban trees produce wood, which can be harvested and sold (Nowak et al., 2019).	Urban timber yields (kg/ha)(Nowak et al., 2019, Liquite et al., 2016) Urban crop yields (kg/ha) (Payen et al., 2022)
Water capture and reuse	Natural systems increase groundwater recharge and water storage. Thereby securing controlled release of water flows, which can provide cities with drinking water and water for other uses (Gómez-Baggethun et al. 2013). Capturing and reusing stormwater can be used for local irrigation, significantly reducing potable water demand (Alves et al., 2018) Also, rainwater that falls on roofs can be captured in storage tanks. This water can later be used for watering the garden, flushing the toilet, or showering. This will reduce drinking water demand and costs for citizens (Woods-Ballard et al., 2015)	Surface area (m^2) (Nachshon et al., 2016) storage capacity (m^3) (Nachshon et al., 2016, Watkin et al.,2019)
Habitat for biodiversity	Urban ecosystems play an important role as refuge area for many species, helping reduce the global loss of biodiversity (Muller et al., 2010). Nature-based solutions provide new nature in the area and thus new habitat for wildlife and various plant species. This can lead to a higher diversity of animal and plant species in the area, improving local biodiversity and ecology of the urban environment.	Shannon diversity index (Moore & Hunt, 2012, Liquite et al., 2016) Expert judgement about biodiversity (Liquite et al., 2016, Watkin et al., 2019) Habitat connectivity (Donati et al., 2022)

Table 5: Description of individual ecosystem service, their relationship with NBS, and examples of performance indicators / proxies to quantify the given ES.

Ecosystem disservices	Service description with link to NBS	Examples of performance indicators / proxies to quantify EDS
Pollen allergies	Vegetation that produces pollen can cause allergic reactions. Pollen can cause serious health problems for persons with asthma (Lyytimäki et al., 2008).	Allergic potential of vegetation (Doran & Haase, 2019)
Habitat competition with humans	The ability of ecosystems to accommodate species harmful or unpleasant to humans (Campagne et al., 2019). Urban vegetation and waterbodies can attract flora and fauna that can reduce mental health by being annoying, frightening or disgusting due to certain sounds, smells, behaviours (Lyytimäk & Sipilä, 2009; Doran & Haase, 2015; Wu et al., 2021). Also, wildlife can be harmful by attacking or biting humans (Campagne et al., 2019). These encounters such as snake bites, kill over 100,000 people a year, mostly in the global south (Sitas et al., 2021)	Number of undesired/dangerous species (Doran & Haase, 2015)
Animals as disease vectors	Diseases transmitted by animals. For example, mosquito's carrying dengue or malaria, wild animals or stray dogs and cats carrying rabies, birds carrying avian influenza or ticks transmitting Lyme (Lyytimäki et al., 2008; Lyytimäk & Sipilä, 2009, Wu et al., 2021). NBS involving open water surfaces and water vegetation, such as wetlands and retention ponds can increase mosquito populations, thus enhancing the risk of infection by diseases such as dengue fever and malaria (Ferreira et al., 2020, Zhao et al., 2015, Finlayson et al., 2015).	Increases in the number of patients of flora and fauna related diseases (Wu et al., 2021) Geographical occurrence of diseases (Doran & Haase, 2015) Mosquito population density (n/m^2) (Zhao et al., 2015) Tick population density (n/m^2) (Uspensky, 2014) Number of stray cats and dogs (n/m^2) (Uspensky, 2014)
Damage to infrastructure	Biological activity causes damage to build structures. Such as decomposition of construction wood by termites or microbial activity, tree roots braking up pavements and sewers, bird faeces accelerating corrosion, or animals digging nesting holes (Lyytimäk & Sipilä, 2009). Whole trees or tree branches can fall during storms, damaging houses, cars, and injuring people. Leaves falling from trees can increase the breaking distances of trams and cars causing accidents (Lyytimäki et al., 2008; Gómez-Baggethun et al., 2013).	Number of aged trees (Doran & Haase, 2015) Percentage of tree species susceptible to damage (Lyytimäki et al. 2008) Tree root structure (Doran & Haase, 2019) Amount of affected infrastructure (Doran & Haase, 2015)
Aesthetical issues	Aesthetical issues consist of all ecosystem structures or processes that can negatively impact people's aesthetical values. Extensively or poorly managed areas can be perceived as ugly, unpleasant, or unsafe (Lyytimäk & Sipilä, 2009; Gómez-Baggethun et al. 2013; Doran & Haase, 2015), especially by woman at night-time (Lyytimäk & Sipilä, 2009). Bird and dog faeces are seen as aesthetical problems (Lyytimäk & Sipilä, 2009). Vegetation can block views. Trees near building reduce the visibility from windows (Gómez-Baggethun et al. 2013).	Area of non-illuminated green spaces (Doran & Haase, 2015) Number and size of trees near buildings and roads (Doran & Haase, 2015)

Table 6: Description of individual ecosystem disservices, their relationship with NBS, and examples of performance indicators / proxies to quantify the given ES.

Cost criteria	Criteria description and link to NBS	Example of performance indicators / proxy to quantify cost
Land costs	Land costs are the capital costs related to both direct land acquisition costs and indirect land-use opportunity costs. Different kinds of NBS need different surface size requirements to be implemented and function properly. For example, street trees or green roofs do not require space that could have been used for other purposes. While NBS such as wetlands or parks require a lot of space, which could have been used for other purposes such as housing or industrial activities. This competition of land use induces an indirect economic tradeoff, captured as land use opportunity costs. The direct cost related to land requirement for NBS are reflected as land acquisition costs.	Space requirement of solution (m^2) Land prices ($/$m^2$)
Construction costs	All capital costs related to building / developing the NBS, excluding the land acquisition costs.	Construction cost of solution ($/$m^2$)
Operation and maintenance cost	All ongoing costs of the NBS after the solution is implemented. Operation and maintenance costs refer to all the material costs, salaries of personnel, and cost of replacements parts required to keep the NBS operational and well maintained. Maintaining the required performance level of the NBS over time.	Maintenance cost of solution ($/$m^2$) Operational cost of solution ($/$m^2$)

Table 7: Description of cost criteria, their relationship with NBS, and examples of performance indicators / proxies to quantify the cost criteria.

3.3.2 Development of the scoring matrices

To develop scoring matrices, all NBS were assigned scores based on the potential effect each solution has on the criteria (ES, EDS, and cost). The scoring of the criteria was performed using a 0 – 5 scoring system. A value of zero indicates that the NBS is not able to improve a given ES or induce a potential EDS. For the benefits (ES), a value of 5 indicates that the NBS has a very high potential to address and improve a certain ES. For the disbenefits (EDS), a value of -5 indicates that the NBS has a very high potential to induce a negative impact. For the cost criteria a value of zero indicates no costs, while a value of -5 indicates very high costs relative to other NBS.

To assess the potential NBS performance on the criteria, a literature search was conducted on articles that assess or report quantitative scoring data on similar NBS and criteria as used in this MCA framework. Articles were searched by informing the data in previously conducted MCA frameworks as found in the literature review and utilizing the snowball effect to find additional sources.

Table 8: Score values with qualitative descriptions.

Scoring system ES	**Description**	**Scoring system EDS**	**description**
0	No effect	**0**	No costs / effect
1	Very low positive potential effect	**-1**	Very low costs / negative potential effect
2	Low positive potential effect	**-2**	Low cost /negative potential effect
3	Medium positive potential effect	**-3**	Medium costs / negative potential effect
4	High positive potential effect	**-4**	High costs / negative potential effect
5	Very high positive potential effect	**-5**	Very high costs /negative potential effect

Six papers that met the criteria were selected to score the ES (Jia et al., 2013; Alves et al., 2018; Ruangpan et al., 2021; Croesser et al., 2021; Castellar et al., 2021; Sarabi et al., 2022). The scoring data was obtained by requesting the data from the authors or extracting it directly from the publications. All scoring data could directly be used, since the papers made use of the same 0-5 scoring scales. Only the work of Castellar et al., 2021 used a scoring scale of 0-1, so this data was first normalized by multiplying all scores with a factor 5. The overall performance score of each NBS on a specific ES was calculated by taking the average value of the assigned scores of the six papers.

No direct scoring data on the ES noise attenuation, carbon sequestration and the cost criteria could be found. Thus, these criteria were scored by searching for qualitative and quantitative data regarding the performance of the criteria, normalizing the assigned quantitative values on a scale from 0 to 1 to create an index (equation 1) and assigning scores from 0 to 5 based on the corresponding of the index factors to the intervals shown in table 9. For the criteria operation and maintenance costs, and construction costs the mean cost values per m^2 in cost ranges per NBS were taken. Values for land acquisition were described qualitatively and converted into corresponding scores.

Table 9: Normalized index range intervals and corresponding scores.

Qualitative value	Range intervals normalized index values (I_{nc})	Score
None	0	0
Very low	0,01-0,20	1
Low	0,21-0,40	2
medium	0,41-0,60	3
High	0,61-0,80	4
Very high	0,81-1,00	5

$$I_{nc} = \frac{x_{nc}}{Max(x_c)} \quad (eq.1)$$

I_{nc} = Normalized assessment index for NBS n and criteria c.

x_{nc} = Quantitative value for NBS n and criteria c.

$Max(x_c)$ = Maximum quantitative value found of all NBS in criteria c.

Score values per NBS for noise attenuation, carbon sequestration, infrastructure damage, habitat competition, disease transmission, and allergies were assigned based on assumed landcover types of the NBS with the same classification used in the respective source data. This assigning of landcover types was done based on experts' judgment of the researcher. For example, the NBS afforestation was assigned the land cover type "woodland," and street trees were assigned the land cover type "hedgerows, tree alignments." In the case of NBS types characterized by a mix of land covers (e.g., Stream daylighting, which was assumed to have a mix of water's edge vegetation and running water), the ES and EDS values were weighted in terms of assumed percentage shares of the NBS area occupied by each land cover.

No data on the criteria aesthetical issues could be found. Thus, these scores were estimated based on expert judgement using indicator proxies. The detailed methodology for deriving criteria scores related to noise reduction, carbon sequestration, cost and all the EDS are described in appendix A.1 and A.2

Remaining data gaps (10 out of 264 data points) in the ES matrix were filled in by using qualitative scoring data from the factsheets of NWRM (2015) (7 data points) and based on the author’s expert judgement (3 data points). Since the NRWM factsheet data is qualitative (low/medium/high), the decision was made to only use this source to fill in the gaps and not use this data for the whole dataset (thus overlapping with other scores). The unprocessed and normalized scoring sheets and on ES, EDS and cost and corresponding literature sources used are shown in Appendix A.3

3.3.3 Criteria weights

In Multi-Criteria Analysis (MCA), criteria often have varying levels of importance. To quantify the relative importance of these criteria, weighting is applied. This is a crucial step in any MCA framework. In order to obtain quantitative data on the perceived importance of the different ES and EDS, a citizen questionnaire was developed.

This framework is the first application of an MCA framework for the selection of NBS that incorporates public stakeholder weighting in the decision-making process by allowing citizens to derive weights for the criteria in the MCA tool. Integrating public perceptions is thought to improve the outcome of the decision process since it enables better incorporation of public demands regarding local environmental and social concerns. This may help to select solutions that are understood and desired by citizens and increases public support for NBS (Shen & Wang, 2013; Derkzen et al., 2017; Miller et al., 2019; Aubert et al., 2020).

The ratio assignment technique (questioning method for assigning weights) used in this MCA to obtain the perceived importance of ES and EDS by citizens was DAT (Direct Assignment Technique). DAT asks participants to score each criterion over a finite scale (direct assignment), such as Likert scales. DAT is the most straightforward weighting technique among the commonly used Ratio Assignment Techniques (Ezell et al., 2021). Its relative straightforwardness and simplicity was thought to increase the likelihood of participant compliance, minimize errors, allow for unassisted conduction of the process, and make the method easily accessible for all stakeholders and age groups. Therefore, DAT was selected as the method to obtain weight input from the public (citizens). A more detailed explanation why this method was selected can be found in appendix B.1.1.: Choosing the weighting method.

The criteria were weighted by asking citizens to assign relative importance levels to all ES on a 7-point Likert scale. The weight scores in numbers were replaced with descriptive texts indicating the level of importance. For the EDS, the level of importance was phrased as 'level of concern'. Detailed information about the development of the questionnaire, the required sample size, and its execution can be found in appendix B. The questionnaire itself is provided in appendix C.

Table 10: Quantitative weight scores and descriptions used in the questionnaire using a 7-point Likert scale.

Quantitative weight score	Descriptive text ES	Descriptive text EDS
0	No importance	No concern
1	Very low importance	Very low concern
2	Low importance	Low concern
3	Neutral	Neutral
4	Important	Concerned
5	Very important	Very concerned
6	Extremely important	Extremely concerned

The cost criteria are weighted by governmental decision-makers since they control the budgets on NBS implementation. The weights for the cost criteria are obtained through interviews conducted with local decision-makers. During these interviews, the decision-makers are asked to verbally indicate the level of importance of the cost criteria (See appendix E.2.) and transferring the obtained answers to the same quantitative weight scores as in table 10. The weight scores of all criteria are obtained by calculating the mean value of all survey responses per criterion. For the cost criteria alternatively a focus group can be organised to get consensus on the overall cost criteria weights by all participating decision-makers and normalizing this output.

The overall weights are calculated by normalizing the obtained mean weight scores. This is done by dividing the mean weight score by the sum of the weight scores of all criteria (Ezell et al., 2021).

$$Wn_c = \frac{ws_c}{\sum ws_c} \qquad (eq. 2)$$

Where ws_c is the original weight score and Wn_c is the normalized weight of the criteria (c).

3.3.4 Measure Ranking

Each measure is prioritized based on suitability by calculating total scores that combine the data from the scoring matrix with the derived weights obtained from the survey. The overall score, which is used to rank the measures when using a linear additive model, is calculated using the following method.

First, it is important to normalize the assigned weights and criteria scores (equations 2 and 3) so that all values are distributed on a common scale between 0 and 1.

$$Sn_c = \frac{S_c}{5} \qquad (eq. 3)$$

Where S is the original score, and Sn is the normalized score for criterion (c).

Next, the score of each measure can be calculated as the sum of all normalized ES criteria scores multiplied by their corresponding normalized weights, minus the sum of all normalized EDS and cost criteria scores multiplied by their corresponding normalized weights. The ecosystem services are assigned a positive score since they represent the positive effects of implementing NBS. The EDS criteria are assigned negative scores since they represent the negative effects of implementing NBS. Cost can also be seen as a negative effect of implementing NBS, and therefore negative scores are assigned to the cost criteria as well.

$$NBS\ score = \sum_{n=1}^{11}(W_{es} * S_{es}) - \sum_{n=1}^{5}(W_{eds} * S_{eds}) - \sum_{n=1}^{3}(W_{cost} * S_{cost}) \qquad (eq. 4)$$

Where W_{es}, W_{eds} and W_{cost} are the normalised weights and S_{es}, S_{eds} and S_{cost} are the normalized scores of the criteria for the ES, EDS, and cost respectively.

3.3.5 Sensitivity analysis

As a final step a sensitivity analysis is conducted to assess the stability and reliability of the results obtained from the analysis. The sensitivity analysis was done on the criteria weights, since they pose a larger source of uncertainty than the scores. By analyzing how other criteria weights would affect the overall ranking of the selected NBS, the range of possible results can be determined. This information is useful for decision-makers since it sheds light potential weaknesses or limitations in the analysis regarding the ranking of measures.

A common approach is to keep all variables in the model constant except for the one being tested. This variable is then varied over its minimum and maximum range to determine how much impact it has on the overall model. Due to the large number of variables (19), this becomes unfeasible since than 2^{19} combinations must be made. Therefore, Monte Carlo method was applied to conduct the sensitivity analysis, varying all weights at the same time within their total range (0-6), and within one standard deviation. The sensitivity analysis sheds light to what extent the uncertainty and disagreement of the weights given by the survey participants (proxied in terms of standard deviation) makes a difference to the final scores and ranking, and what the minimum and maximum range of possible results with other weights could have been.

4 Results

In this chapter, the NBS selection framework will be put into practice by testing the framework on the selected case study of Tam Ky city in Vietnam. The results are described in the same chronological order as the steps taken for the framework, as described in the methodology section.

4.1 Screening solutions results

4.1.1 Identify local context and site characteristics

A site visit was conducted from December 19, 2022, until December 22, 2022. During this site visit, three interviews with the local government were conducted, and a visual site inspection was held to identify the case study setting, context, hazard identification, and site characteristics. The output of this step resulted in a case study area description.

Table 11: Names and profession of the interviewees. On 20 December 2022 three interviews with local government officials were held.

Name	Expertise/background
Le Kieu Thanh	Environmental engineer at the Quang Nam department of natural resources and environment (DONRE).
Nguyen Van Huong	Hydrologist at the water division of the Quang Nam department of natural resources and environment (DONRE).
Nguyen Quoc Ky	Project manager at project management unit (PMU) of transportation that manages the world bank project for flood protection for Tam Ky area.

4.1.1.1 Background

Urbanisation in Vietnam has increased by 7% in the last 10 years (Statista, 2023). Because of this increased urbanisation, the vulnerabilities of urbanisation caused by climate change impacts will also further increase. The effects of urbanisation and climate change can already be seen in mega cities such as Ho Chi Min City in Vietnam, which is now regularly affected by flooding, sometimes several times a year (Dolman & Ogunyoye, 2018). Also, other smaller secondary cities in Vietnam face regular flooding. An example of one of these cities is Tam Ky. Tam Ky experiences both fluvial and pluvial flooding in the area.

There were 14 fluvial floods on the Ban Thach and Tam Ky River from 1999 until 2021 (University of Danang, 2021). Whereas 2018, 2020, and 2021 floods caused widespread flooding in residential areas for up to a meter deep (Newsbreezer.com, 2021; University of Danang, 2021). Because of this, last March 2022 Royal HaskoningDHV gave strategic advice towards the Provincial Chairman of Quang Nam and the World Bank on flood management options to reduce fluvial flooding for Tam Ky city and the surrounding area. This research and advise focussed on the hydraulic (river) system surrounding the city and was focused on exploring solutions with the implementation of NBS. The reason for the interest in NBS, is due the fact that one of the requirements the Quan Nam province needs to fulfil to get a loan from the Worldbank for this project, is that also NBS options should be assessed. Various fluvial flood risk reducing NBS with cost benefit analysis for outside the city were modelled and proposed.

One already implemented solution to protect Tam Ky from fluvial flooding is a newly constructed dike around the city side close to the river (See Figure 8). However, the dykes reduce the outflow capacity of the urban drainage system, which leads to an increase in pluvial flooding in the area. Which even without the dike was already a major problem for the city. Because of this, additional storage and peak flow delaying solutions for inside the city are of importance to mitigate or at least reduce pluvial flood risk for Tam Ky (Hoang et al, 2022, internal communication employees). During the recent research of RHDHV, no research was done on pluvial flooding in the urban area. Because of this, RHDHV has a future interest in how to make the city less susceptible to pluvial flooding with the implementation of NBS. Therefore, the midsized city of Tam Ky was selected to test the current NBS selection framework on.

Figure 7: Flooding of the City of Tam Ky in 2020 and 2021. (Source: Newsbreezer.com)

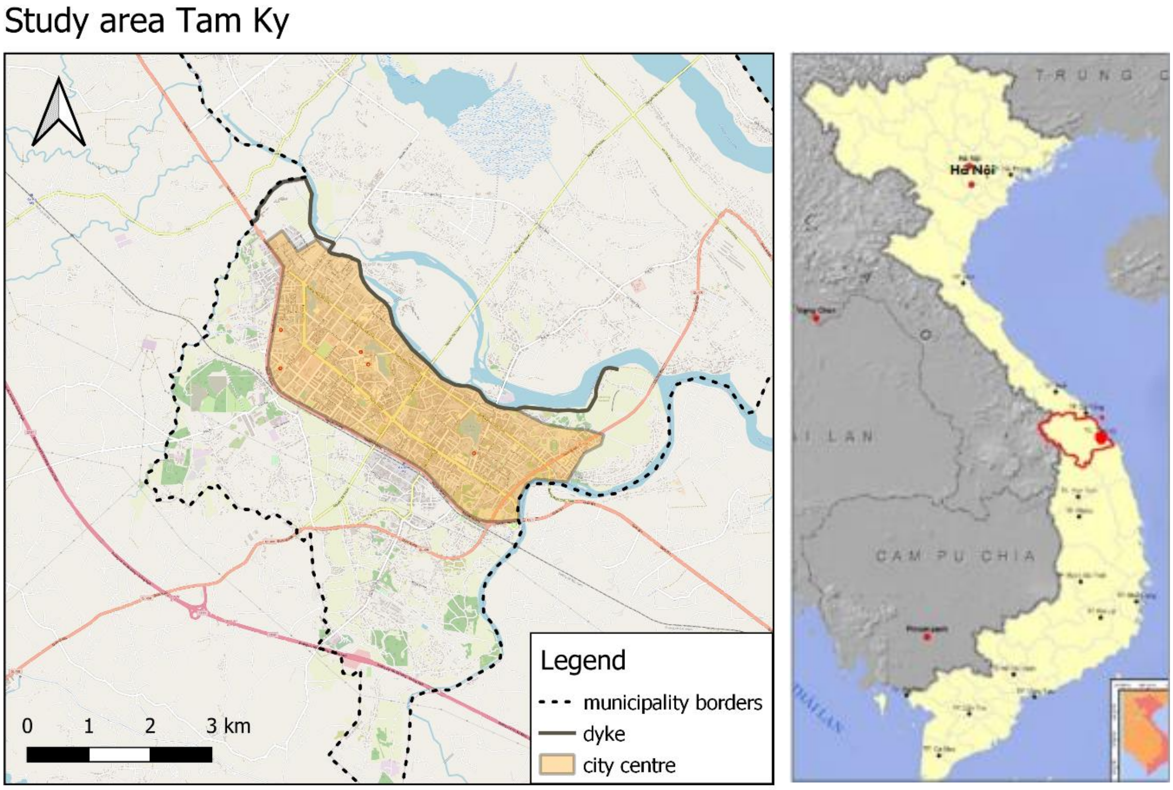


Figure 8: Right: The urban center of the city of Tam Ky (orange). The newly constructed dike around the city centre of Tam Ky to protect it from fluvial flooding. The dykes reduce the outflow capacity of the urban drainage system. This means that direct rainfall on the city cannot always be adequately discharged and is likely to cause overflow of the urban drainage system into the streets, excavating the already existing pluvial flooding issues in the area. Left: Map of Vietnam showing the location of the city of Tam Ky (red dot) and Quan Nam province (red border). Source: Urban core and municipality boundaries from: Quang Nam Province Department of Construction, Quang Nam Institute for Rural and Urban Planning. Dyke outline: field visit

4.1.1.2 *Case study area description*

Tam Ky is the capital city of the Quang Nam province in the middle of the country (see Figure 8). The city is located in the southeast of the province near the coast. The large Ban Thach River flows through the middle of the municipality. The municipality's borders stretch from the coast in the north to the Phu Nin reservoir lake in the south. The eastern and western borders of the municipality are defined by the Tam Ky and Phu Ninh River, respectively. The municipality covers an area of 93 km^2 and has a total population of 113,000 people. The population density in the municipality is highly heterogeneous, with most people inhabiting the central wards in the urban core on the southeast side of the Banh Tach River (see Figure 9). This urban core was selected to test the NBS selection framework. The urban core has an area of 17 km^2 and an average population density of 64 persons/ha (Van Ahn et al., 2016). This urbanized core developed due to spatial boundaries in the area. The National Highway 1A limits urbanization in the southern and western parts of the city, while the Ban Thach and Tam Ky River limit urbanization in the northern and eastern parts of the city. Existing agricultural settlements in the southern area restrict further urbanization to the south due to the relatively expensive land acquisition and extensive procedures involved in buying up agricultural settlements in that area (Van Ahn et al., 2016). The upstream Phu Nin reservoir lake supplies all irrigation channels and the drinking water supply for the city. As a result, there are no groundwater abstractions in the urban core, and as far as known, no issues with subsidence (Interview notes).

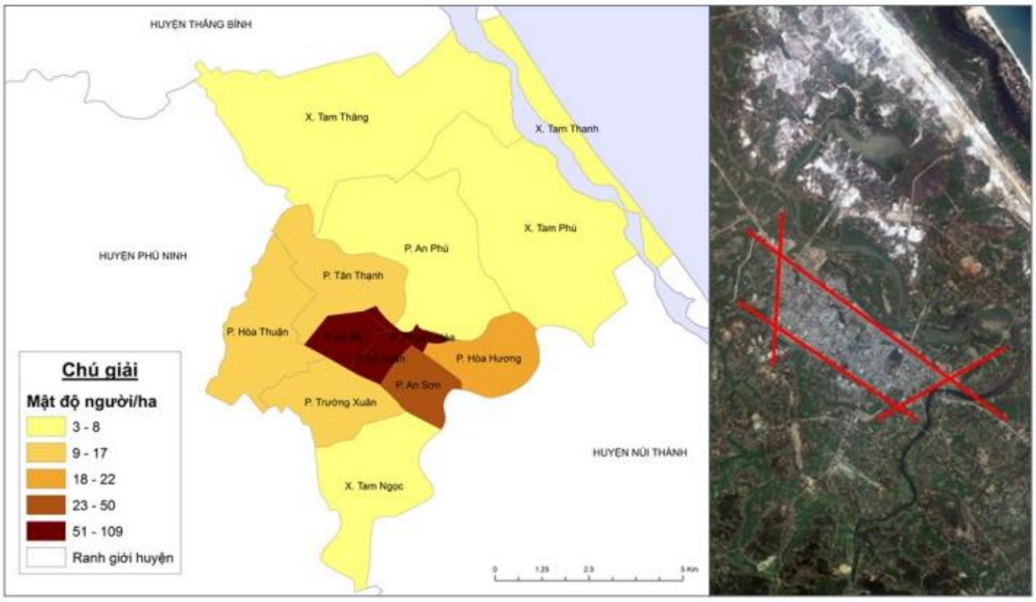


Figure 9: Left: Population density per ward in persons/ha. Right: Urban core of Tam Ky visible from satellite imagery. The red lines indicate the global boundaries of the urban core. Source: Van Ahn et al., 2016

4.1.1.2.1 <u>The drainage system</u>

The urban core of Tam Ky is located at the downstream end of two catchments of 28,75km^2 and 3,85 km^2 respectively. Between these catchments lies another smaller catchment. The water from all three catchments discharge via the urban drainage system to the Banh Thach River. (See figure 10). The outflows are protected with large orifices to protect the city from backwater effects during high river water levels. To accommodate the floodwaters from upstream catchments, a network of channels and large retention ponds are constructed to accommodate a large volume of water in case of heavy precipitation events combined with high-water periods in the Banh Thach River, which can temporarily obstruct the outflow capacity of the urban drainage system. To accommodate for the floodwaters coming from the small catchment on the right, an initial design for a flood diversion channel has been made by the Quang Nam Climate Resilient Urban Services Project funded by the Asian Development Bank. The diversion should divert the water from the small catchment on the right to the Tam Ky River, alleviating this type of pluvial flooding in Tam Ky. According to local government officials, flash floods due to rapid rising water levels in the streams of the two small catchments do not occur.

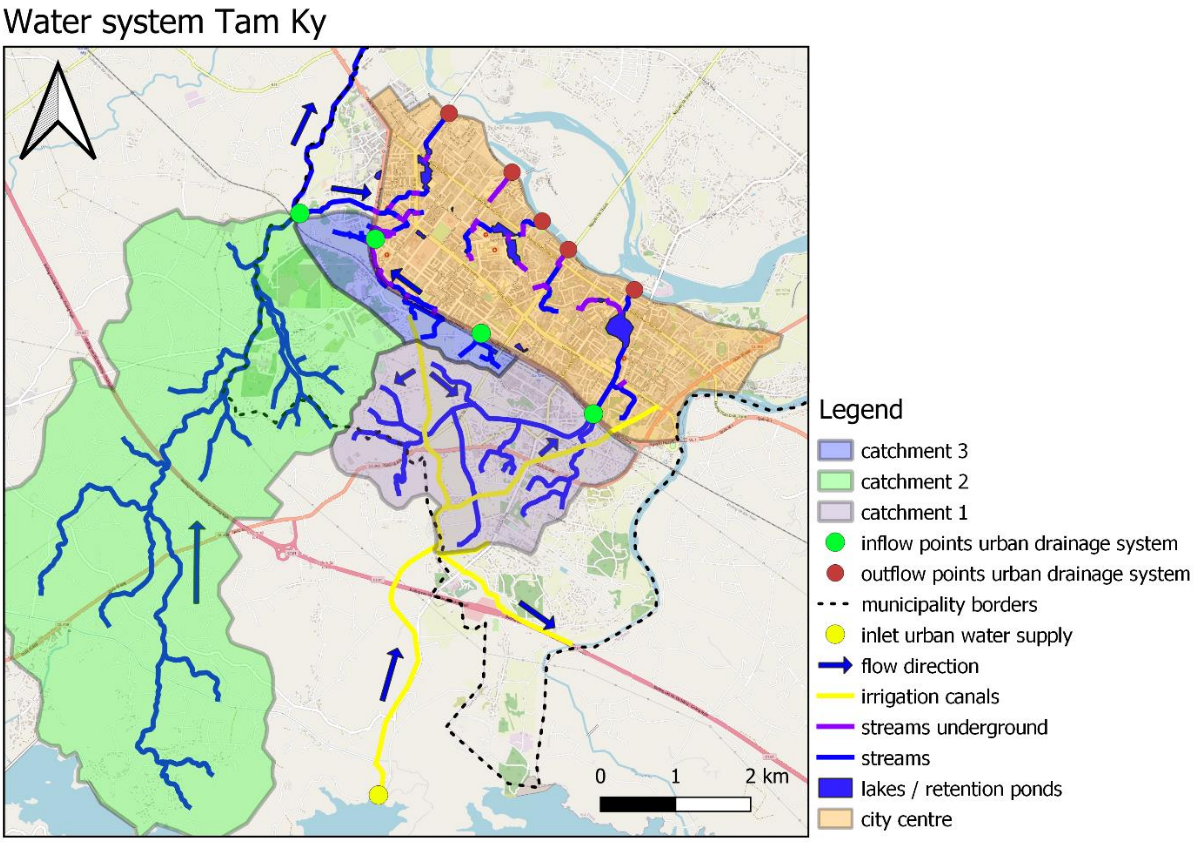


Figure 10: Water system of Tam Ky. Stormwater from three small catchments drain into the urban drainage system (green points), and discharge via this network of (underground) streams and retention ponds to the Banh Thach River (red points).

The area experiences a tropical monsoon climate characterized by a distinct wet and dry season. The monsoon season typically lasts from September to January, bringing tropical storms and typhoons, with the highest frequency occurring from July to September. These weather phenomena result in heavy precipitation events, reaching a peak monthly precipitation of 560 mm in November (Climate Tam Ky, Vietnam, 2023). These heavy precipitation events during the monsoon lead to pluvial flooding issues. The urban drainage system exceeds their capacity causing pluvial flooding in low elevated areas for several hours to days (Hoang et al., 2022). These pluvial floodings occur due to an inadequate urban drainage system (SCDV Tam Ky, 2013). The combined sewer system stems from 1997. Due to rapid urban development and fast-growing pace of the city, the drainage system has become too small to accommodate for the rainstorms. Both pipes and culverts are designed to small, resulting in frequent occurring pluvial flooding throughout the city. Which are especially prominent in the older parts of the city and on Hung Vuong Road, at which intense but sort inundation occurs throughout the whole area after every heavy precipitation event (Interview notes). Furthermore, the drainage system lacks sufficient subbranches to cover the entire drainage area, contributing to its ineffectiveness (Interview notes). Other common causes of drainage system failures in Tam Ky include blocked culverts due to litter and deteriorated pipes, resulting in flow disruptions or blockages (Interview notes; SCDV Tam Ky, 2013).

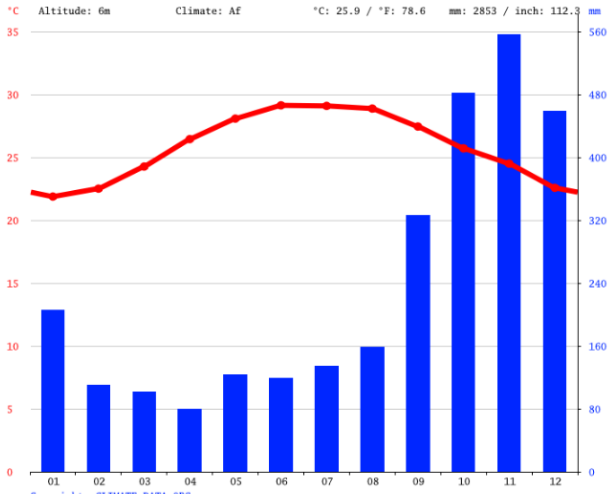


Figure 11: Average climate of Tam Ky. The red line indicates the average temperature in °C. The bars indicate the average rainfall in mm per month.
Source: climate-data.org/asia/vietnam/quang-nam-province/tam-ky

4.1.1.2.2 Environmental hazards

All residential wastewater and storm water from the combined sewer system flows untreated into the Banh Tach River, since there is currently no WWTP in Tam Ky. As a result, the river becomes polluted, and the existing retention ponds also suffer from heavy pollution. This pollution leads to unpleasant odors and a decline in ecological activity within the ponds. Especially in the dry season, when the retention time of the water is longer, these effects intensify (citizen interview notes). When sewage water inundates the streets, it exposes people to contaminated water, which poses serious health risks for the residents (SCDV Tam Ky, 2013).

At the southwest part of the urban core an industrial area is situated on high terrain. The high terrain indicates the presence of weathered igneous rocks (SCDV Tam Ky, 2013), consisting out of sand and gravel. The sand and gravel extracted from this area are used for concrete production in several factories within the industrial area. As a result of these activities, large trucks carrying sand and gravel frequently pass through the city center, causing dust and noise pollution (Interview notes). Construction and other industrial activities also contribute to noise and air pollution, although these effects are primarily localized around the industrial site. According to air and noise quality monitoring data from the PMU of transportation in 2013, noise pollution exceeds national standards for an average of eight months per year, while air pollution in Tam Ky exceeds national standards for an average of four months per year (SCDV Tam Ky, 2013). Recent interviews with local government officials indicate that these environmental issues have not been resolved to date.

4.1.1.3 Local site characteristics for screening

The urban core of Tam Ky is built on a river plain 2 to 4 m above sea level. Elevated. The soil in this area primarily consists of alluvial clays and silts, and the average drainage slope in the city center is 0 to 5%. During the site visit it became clear that the soil in the city of Tam Ky consist of clay soils. This was observed at excavation sites and vacant lots throughout the city. To conduct a quick assessment on soil infiltration rates, a bucket of water was poured over bare soil. After returning 1 hour later to the same location, the same pool of water could still be seen. Indicating that soil permeability on site is low. In other areas where vegetation was removed due to recent construction, bare clay soils were clearly visible with significant pooling of rainwater, further indicating low permeability (See figure 13).

During interviews with local government officials, it was confirmed that the entire case study area consists of the inspected clay and loamy clay soils for the top few meters. All soils in the case study area were assessed as soil type C-D, indicating low to very low infiltration rates. The water table depth was estimated at 1,5 to 2 meters.

Table 12: Obtained site characteristics for screening.

Site characteristics for screening	result
Area drainage slope °	0 – 5 °
Water table depth	1 – 2 m
Soil type	Clay / loamy clay soil, group C/D
Hazard type	Pluvial flooding

Figure 12: Soils and water table visible on excavation site. The light brown reddish soil is artificial supplemented sand to elevate the ground level for construction. The grey clay underneath (picture left) is the original soil. The water table depth is at the same level as the surface water, which was estimated on 1,5 – 2 m from ground level.

Figure 13: Vacant lots inside the city of Tam Ky. Rainwater is visually pooling a couple of hours after a rainstorm due to low permeable clay soils. The hydrologic soil types for Tam Ky were estimated in class C or D.

4.1.2 Provide database measures: Pre-screening database RECONECT

The filter options for the case study area were obtained by the interviews held with local decision-makers in Tam Ky and background information about the project and case study area. The following filters were applied for the case study area:

Table 13: Selected filters in the RECONECT measure selector tool. Adapted from: http://www.reconect.eu/services-platform/measure-selector-tool

Filters	Options selected
Type of measure	NBS
Hazard type	Pluvial flooding
The affected area	Urban area
Potential location for measures	Urban area
Project type	New measures
Land surface type relevant for implementation	Artificial surfaces Agricultural land Forest and semi-natural areas Water bodies

By running the tool, a list of 26 potential applicable different measures were generated. The list of measures selected is shown in table 14.

4.1.3 Screen data base on local site characteristics and boundary conditions

A table stating the boundary implementation conditions for all pre-selected NBS was developed (Table 14). This preselected list of NBS was screened based on the identified local site characteristics that may impose implementation constraints (Table 15). Drainage slopes and water tables were not found to be limiting factors for the case study area. All measures were eliminated based on hydrological soil type. As a result of this screening, a list of 18 applicable NBS for the case study area was obtained, which will be used for further analysis. The applicable measures for the case study are indicated in green in the table below.

Table 14: Implementation constraints of pre-selected NBS. The measures indicated in green pass the screening of considered implementation constraints.

	Measures*	min-max applicable Slope (%)	Minimum distance to groundwater table (m)	Applicable in soil type
1	Retention ponds	<15	>1.5	A-D
2	Rainwater harvesting	-	-	-
3	Detention basins	1 - 15	>1.5	A-D
4	Natural open water channels and rills	1- 10	-	A-D
5	dry swale / wadi / grassed swale	1 - 10	>1.5	A-D
6	Bio swales	1 - 10	>1.5	A-D
7	Wetland channel (Wet swale)	1 - 10	>0	A-D
8	**Rain Garden**	<10	>1.8	A-B
9	**Soakaways**	<15	>1	A-B
10	Extensive green roofs	<4**	-	-
11	Intensive green roofs	<4**	-	-
12	Wetland	1 - 15	>1.3	B-D
13	Green walls	-	-	-
14	Parks	-	>0.6	A-D
15	Floodable waterfront parks	-	>0.6	A-D
16	**Permeable pavements**	0.5 - 5	>3	A-B
17	**Filter trenches**	1 - 5	>3	A-B
18	Street trees / green streetscape	<10	>1	A-D
19	natural bank stabilisation	-	-	A-D
20	Green deculverting/ Daylighting	<20	-	-
21	Afforestation / Urban forest	<20	>0.6	A-D
22	Filter strips	1 - 5	>0.6	A-D
23	**Filter drains**	1 - 5	>0.6	A-B
24	**Infiltration trenches**	1 - 5	>3	A-B
25	**Infiltration basin**	0 - 3	>1.2	A-B
26	**Artificial groundwater recharge**	-	-	A-B

*Some names have been slightly altered from the names in the tool for clarification purposes **Only flat roofs considered. - = no data found / not applicable Sources: *Woods-Ballard, 2015, Jia et al., 2013., Ariza et al., 2019., Sarabi et al., 2022, Li et al., 2020*

Table 15: Considered site characteristics for screening.

Site characteristics for screening	Result
Area drainage slope %	0 – 5 %
Water table depth	1 – 2 m
Soil type	Clay / loamy clay soil, group C/D

4.2 MCA Results

In this paragraph the results of the testing of the MCA part of the framework on the case study area is shown. First the results of the weighting, scoring and ranking steps are stated. At last, the result of the conducted sensitivity analysis is described.

4.2.1 Scoring matrices

On the following pages, the results of the criteria scoring for the selected measures are presented. The performance matrices display the scoring results on a scale from 0 to 5. These matrices indicate the extent to which different NBS can provide ecosystem services and disservices, as well as the performance of the solutions in relation to the three considered cost criteria.

The results reveal that the selected measures can supply a wide range of both ES as well as EDS. The total points allocated to ES and EDS vary significantly across the different measures. Urban forest provides both the most ES (40 points) and EDS (12 points). While natural open water channels and rills supplies the least amount of ES (9 points) and rainwater harvesting techniques supply the least amount of EDS (1 point). The measure with the highest total score is afforestation with 21 points, whereas natural open water channels and rills have the lowest score with -4 points. The average total score among the selected measures is 11,07, with an average of 25 points for ES, 6,7 points for EDS, and 7,33 points for the cost criteria.

The average score for all ES is 2,28. Among the selected measures, Aesthetics receives the highest ES score (3,50), followed by Flood risk reduction (2,94) and Urban heat island mitigation (2,88). Regarding EDS, the average score is 1,35, and no measure receives a score higher than -3, indicating a lack of potential for high or very high negative effects. Pollen allergies have the highest average score (1,63), while infrastructure damage has the lowest score (0,69). For the cost scores construction cost scores on average the highest (2,74), and operation and maintenance cost the lowest (2,18).

The underlying data sources and calculations made to produce the performance matrices can be found in appendix A. In appendix A.3 the general scoring matrices on a scale on 0-5 and the not rounded normalized values for the total measure database can be found. For the ranking calculations these unrounded normalized values have been used (Appendix A.3: Table 28) to prevent data loss. If desired, the user can utilize this more precise data for scoring purposes, as these matrices are already normalized and not rounded to whole numbers.

Table 16: Score values with qualitative descriptions.

Scoring system ES	Description	Scoring system EDS/costs	description
0	No effect	**0**	No costs / effect
1	Very low positive potential effect	**-1**	Very low costs / negative potential effect
2	Low positive potential effect	**-2**	Low cost /negative potential effect
3	Medium positive potential effect	**-3**	Medium costs / negative potential effect
4	High positive potential effect	**-4**	High costs / negative potential effect
5	Very high positive potential effect	**-5**	Very high costs /negative potential effect

Table 17: Performance matrix for selected NBS scored on considered ES criteria.

Selected measures	Short discription of solution	Ecosystem services: Regulating services						Habitat services	Cultural services		Provisioning services		Total ES points measure
		Flood risk reduction	Water purification	Air purification	Carbon sequestration	Noise attenuation	Urban heat island mitigation	Habitat for biodiversity	Recreation	Aestetics	Water capture and reuse	Production of market goods	
Retention ponds	Pond designed with extra storage capacity to collect and hold stormwater runoff.	5	3	1	1	0	2	3	2	3	3	2	25
Rainwater harvesting	Collection and storage of rain from roofs in barrels or tanks.	2	1	0	0	0	1	0	0	1	5	0	10
Detention basins	Dry surface storage basin that can inudate during storm events.	5	1	0	1	1	2	2	3	2	4	1	22
Natural open water channels and rills	Shallow open surface water channels with hard edges to convey stormwater.	2	0	1	0	0	1	2	0	2	0	0	8
Swales (all kinds)	Shallow, linear channels vegetated with grass or shrubs to convey, absorb and slow down stormwater.	4	3	2	1	1	3	3	1	3	1	0	22
Extensive green roofs	Green roof with a thin substrate layer covered with herbaceous vegetation and mosses.	2	2	3	1	1	3	2	2	4	1	0	21
Intensive green roofs	Green roof with a deep substrate layer allowing to grow gardens on rooftops.	3	3	4	3	2	4	3	3	4	1	3	33
Wetlands	Area that's either seasonally or permanently covered by shallow water.	2	4	1	3	2	3	4	3	5	5	1	33
Green walls	A with vegetation covered wall.	1	1	3	2	4	4	2	0	5	0	0	22
Parks	Parks and trees provide green space and recreational area's in the city.	3	4	5	3	3	5	4	5	5	0	1	38
Floodable waterfront parks	Waterfront parks are (recreation) area's alongside waterbodies that are able too inudated during storm events with minimal damage to park infrastructure.	5	2	3	3	3	2	3	4	4	0	0	29
Street trees / green streetscape	Green area's in streets covered by trees and / or bushes.	3	2	5	4	2	5	3	2	4	0	1	31
Natural bank stabilisation	Replacing concrete banks of streams with natural materials and vegetation.	3	4	2	2	2	3	4	4	3	5	0	32
Green deculverting/ Daylighting	Opening up burried watercourses.	3	3	1	1	1	2	4	3	5	2	2	27
Afforestation / Urban forest	Planting of new forest in the urban area.	3	4	5	5	3	5	4	4	5	0	2	40
Filter strips	Gently sloping strips of grass able to convey runoff as overland sheet flow.	1	2	0	1	1	1	1	0	1	1	0	9

*Some names have been slightly altered from the names in the RECONECT database for clarification purposes. Also, the three types of swales: bioswale, grassed swale, and wet swale has been assessed as one solution type since no data on individual swale types could be found and ES/EDS delivery differences between swale types are assumed to be small.

Table 18: Performance matrix for selected NBS scored on considered EDS and costs criteria. The last column shows the total amount of performance points obtained per measure for all criteria.

Selected measures	Short discription of solution	Ecosystem dis-services					Cost criteria			Total EDS points measure	Total cost points measure	Total points measure (ES-EDS-cost)
		Regulating dis-services		Habitat dis-services	Cultural dis-services	Provisioning dis-service	Capital cost		Operation and maintenance cost (m2/year)			
		Animals as disease vectors	Pollen allergies	Habitat competition with humans	Aesthetical issues	Infrastructure damage	Land costs	Construction costs (m2)				
Retention ponds	Pond designed with extra storage capacity to collect and hold stormwater runoff.	2	0	2	1	1	4	1	1	6	6	13
Rainwater harvesting	Collection and storage of rain from roofs in barrels or tanks.	1	0	0	0	0	0	1	1	1	2	7
Detention basins	Dry surface storage basin that can inudate during storm events.	2	2	2	1	0	4	2	1	7	7	8
Natural open water channels and rills	Shallow open surface water channels with hard edges to convey stormwater.	2	2	2	0	1	1	2	1	8	4	-4
Swales (all kinds)	Shallow, linear channels vegetated with grass or shrubs to convey, absorb and slow down stormwater.	1	2	1	1	1	3	1	1	6	5	11
Extensive green roofs	Green roof with a thin substrate layer covered with herbaceous vegetation and mosses.	0	2	1	1	0	0	3	5	4	8	9
Intensive green roofs	Green roof with a deep substrate layer allowing to grow gardens on rooftops.	1	1	1	1	1	0	5	5	5	10	18
Wetlands	Area that's either seasonally or permanently covered by shallow water.	2	2	2	1	0	5	3	3	8	10	15
Green walls	A with vegetation covered wall.	1	2	1	1	1	0	4	1	6	5	11
Parks	Parks and trees provide green space and recreational area's in the city.	1	3	2	2	1	5	5	1	9	11	18
Floodable waterfront parks	Waterfront parks are (recreation) area's alongside waterbodies that are able to inudated during storm events with minimal damage to park infrastructure.	1	3	2	2	1	5	5	1	8	11	10
Street trees / green streetscape	Green area's in streets covered by trees and / or bushes.	2	3	2	2	1	0	3	5	10	8	13
Natural bank stabilisation	Replacing concrete banks of streams with natural materials and vegetation.	2	2	2	1	0	2	3	5	7	10	15
Green deculverting/ Daylighting	Opening up burried watercourses.	2	2	2	1	1	2	5	2	7	9	10
Afforestation / Urban forest	Planting of new forest in the urban area.	3	3	3	3	1	5	1	1	12	7	21
Filter strips	Gently sloping strips of grass able to convey runoff as overland sheet flow.	0	1	1	0	1	3	1	1	3	5	1

4.2.2 Criteria weights

The criteria weights are based on the subjective preferences and perceptions of local decision-makers and citizens of the case study area, reflecting the relative importance of considered criteria. The weights for the ES and EDS were obtained by conducting a citizen's questionnaire in Tam Ky. (see appendix C), while the cost criteria weights were obtained by interviewing local decision-makers working in urban planning and water management for Tam Ky (see appendix E.2.1). From 19 to 22 December 2022 the survey campaign was held, which resulted in 99 citizens participating in the questionnaire and three interviews with local decision-makers. 71 participants were recruited through the paper version questionnaire, and 28 through the online version. A detailed description about the questionnaire development and data collection process can be found in appendix B.

The average weight of all 99 citizen responses was taken to obtain the overall weight per criteria. On average the ES (average score of 3,9) are valued as more important than EDS (average score of 3,4). The spider and bar chart plots (Figure 14: A, B) show the relative importance of all valued criteria on a scale from 0 (no importance) to 6, (extremely important). Figure 14, C shows the distribution of weights after normalizing the weights, where the total amount adds to 100%.

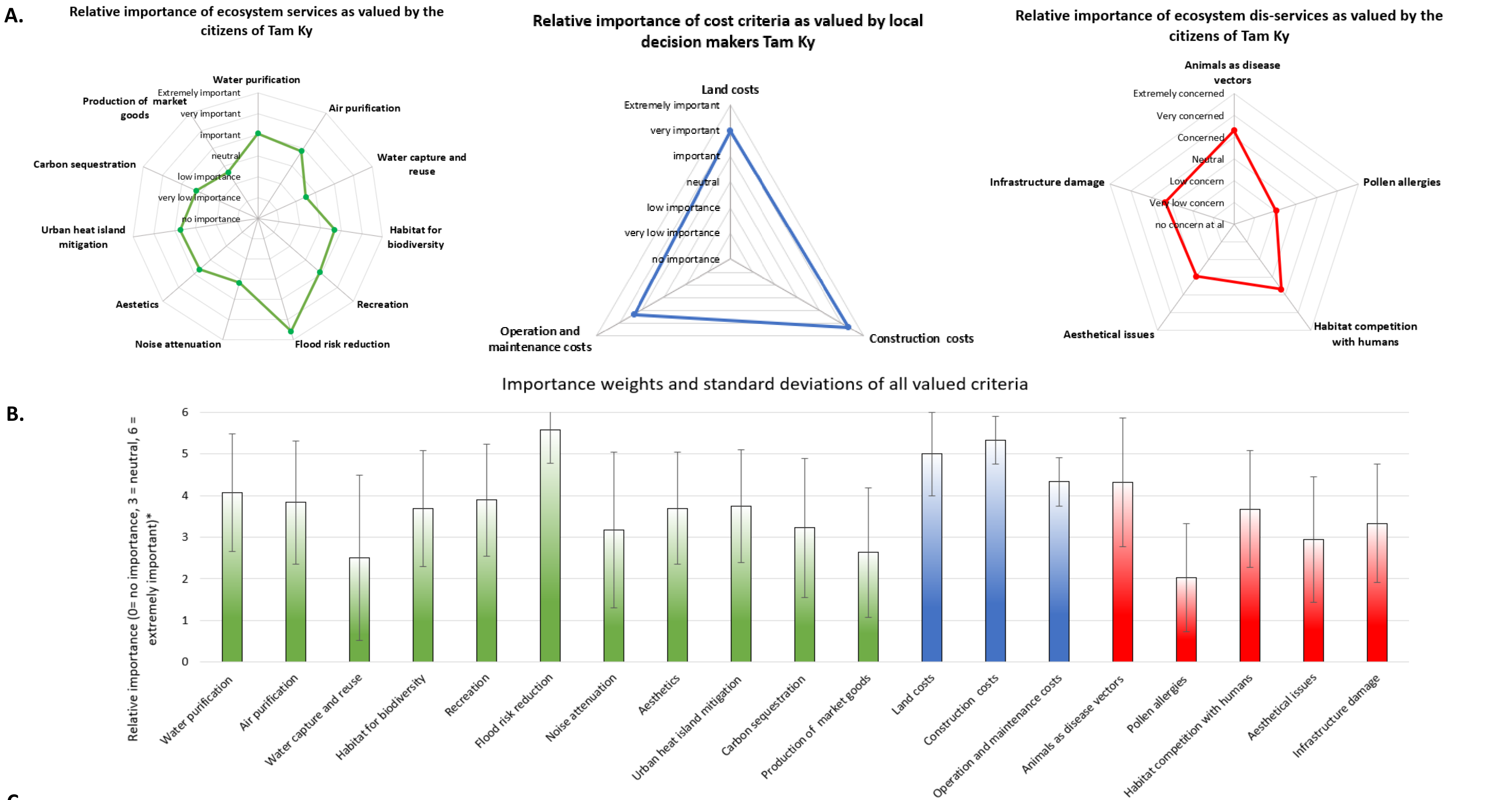
4.2.2.1 Perceived importance of criteria

The results provide insight which ES provided by NBS are most highly valued by the citizens of Tam Ky. The results show that all ES are valued within the range between ''extremely important'' and ''neutral'', indicating that citizens perceive many ES as important. Among the valued ES, flood risk reduction is identified as the most important service to improve for Tam Ky, with a valuation ranging from "very important" to "extremely important" (5.6). This is not surprising considering the significant challenges the city faces with pluvial and fluvial flooding. The most important ES besides flood risk reduction is to improve surface water quality (4,3) and air quality (4,1). These ES are closely followed up in terms of importance by urban heat island mitigation (4,0), recreation (4,0), aesthetics (3,9), and habitat for biodiversity (3,9). Carbon sequestration, noise attenuation, production of market goods, and water capture and reuse are valued statistically significant lower that the other ES. With the provisioning services valued as least important of all services with a valuation of ''neutral''.

For the ecosystem disservices the citizens of Tam Ky have ''high'' to ''very high'' perceived concern that an increase of natural infrastructure due to NBS it the city will lead to more vector-borne diseases such as Dengue (4,5). Also, citizens are somewhat concerned with an increase in nuisance animals and plants, and an increase in infrastructure damage caused by biological activity. Potential aesthetical issues are perceived as having a "neutral" level of concern, while an increase in pollen allergies is considered to be of "low concern."

The three interviewed local decision-makers who valued the importance of the costs of NBS valued the costs regarding the construction of NBS between ''extremely'' and ''very important'' (5,3), Land costs as ''very important (5,0), while the operation and maintenance costs were valued between ''important'' and ''very important'' (4,3).

A.



C.

Criteria	Flood risk reduction	Water purification	Air purification	Carbon sequestration	Noise attenuation	Urban heat island mitigation	Habitat for biodiversity	Recreation	Aestetics	Water capture and reuse	Production of market goods	Land costs	Construction costs	Operation and maintenance costs	Decease transmition	Pollen allergies	Habitat competition with humans	Aestetical issues	Infrastructure Damage
Weight distribution (% of total)	7,9%	5,7%	5,4%	4,5%	4,5%	5,3%	5,2%	5,5%	5,2%	3,5%	3,7%	7,0%	7,5%	6,1%	6,1%	2,9%	5,2%	4,2%	4,7%

Figure 14: Weighting results of the criteria as valued by the citizens and local decision-makers for the Tam Ky City case study area. A. Spider plot chart showing the relative importance of evaluated criteria. B. Bar charts showing relative importance in terms of quantitative scores with one standard deviation. C. Obtained distribution of weights.

4.2.2.2 Standard deviations

The average standard deviation of all ES and EDS is large (σ=1,42), indicating a high variation on the perceived importance of considered criteria by citizens and thus low consensus. Flood risk reduction has the lowest standard deviation, indicating a high consensus among citizens that there is a need for flood risk reduction in the city. Water capture and reuse has the highest standard deviation of all criteria, indicating there is very low consensus among citizens regarding this ES.

When plotting the covariance of variation (Standard deviation/mean weight) against the mean weight, a negative correlation between the weight score and standard deviation can be seen (Figure 15). This relation indicates that with decreasing importance of criteria, the variation on perceived importance increases. Therefore, it suggests a negative correlation between importance and consensus. By plotting the answer distribution of the two criteria with the highest covariance of variation (CV) the high variation among the answers for these criteria is visualised (Figure 16). The figure shows the low consensus amongst citizens for considered ES and EDS.

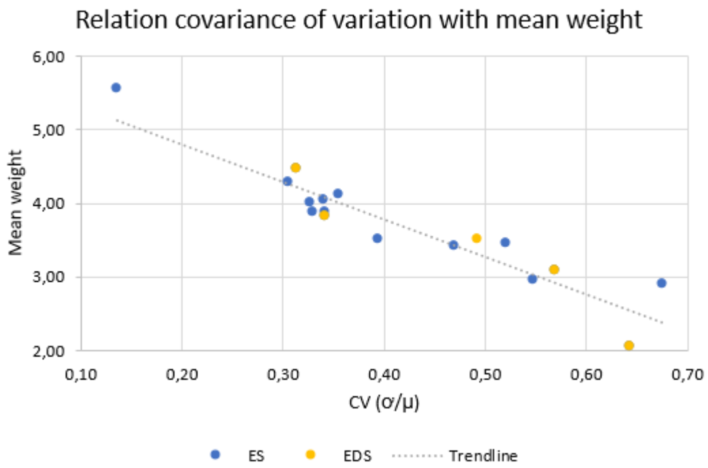


Figure 15: Relation between covariance of variation (CV) against average ES or EDS weights. The lower the criteria are valued, the higher the CV.

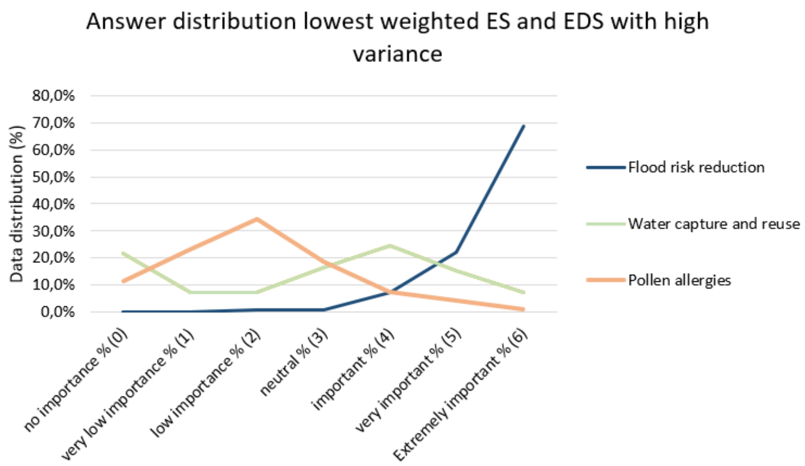


Figure 16: Answer distribution of lowest weighted ES and EDS with highest CV. The figure shows that the consensus amongst citizens is very low for valuing the importance of these criteria. For example, water capture and reuse are valued 22% of the time ''no importance'' and 24% of the time valued ''important''. Also, the highest valued ES (Flood risk reduction) is shown as references for a criterion possessing high consensus amongst citizens.

4.2.2.3 Demographics

Bivariate analyses were conducted on the demographic parameters, age, gender, profession, educational background. Also, differences in responses between the online and paper version and spatial differences were analyzed. This was done to understand how demographic parameters or spatial location are related to the valuation of different ES and EDS. No differences in ES or EDS perceptions among citizens could be found regarding location (e.g., a statistically significant higher valuation in local noise or air pollution for people living near the industrial area). However, for the variable age, statistically significant differences between the assessed age groups were found. In general, a decreasing trend in importance perceptions could be seen, where the youngest age group (<18-25) gave on average the highest ratings to both ES and EDS, while the oldest age groups (56-65+) gave the lowest ratings. The reverse can be seen for flood risk reduction, where the highest valuation is given by the oldest age groups, although this trend is not statistically significant. For all criteria except flood risk reduction, urban heat island mitigation, habitat for biodiversity, pollen allergies, and the sub-criteria ugly and unsafe area's statistically significantly different valuations on a 95% confidence level between the age groups 56-65 and 65+ and the younger age groups (>18-45) were found. For the age group 46-55 only a statistically significant difference in valuation for noise attenuation and animals as disease vectors was found.

The stakeholder group ''retired'' scored significantly lower in comparison to the other stakeholder groups on 10 out of 18 criteria. Similarly, the education group ''prefer not to say'' scored significantly lower on six criteria compared to the other education groups. However, these differences are very likely caused by the same effect, since 100% of retired individuals are in the age groups 56-65+, and 94% of age groups 56-65+ answered, ''prefer not to say'' regarding the question on education. No statistically significant differences between the paper and online version were found after correcting for age. The online version was only filled in by younger participants, while the paper version was filled in by all age groups. When comparing the sample in terms of age groups to the actual age demographics of the Qian Nam Province (figure 17), it shows that age group 25-36 is over-represented in the sample. This suggests that the results are biased towards the age group 26-35, since they have more influence on the overall result than other groups. Because a relation between age and ES/ EDS perceptions was found, it is therefore important to correct for the over-represented group. To address the bias introduced by the over-represented age group and align the sample with the actual age demographics, the dataset was sub-sampled by excluding online responses from the age group 26-35 from the weighting process.

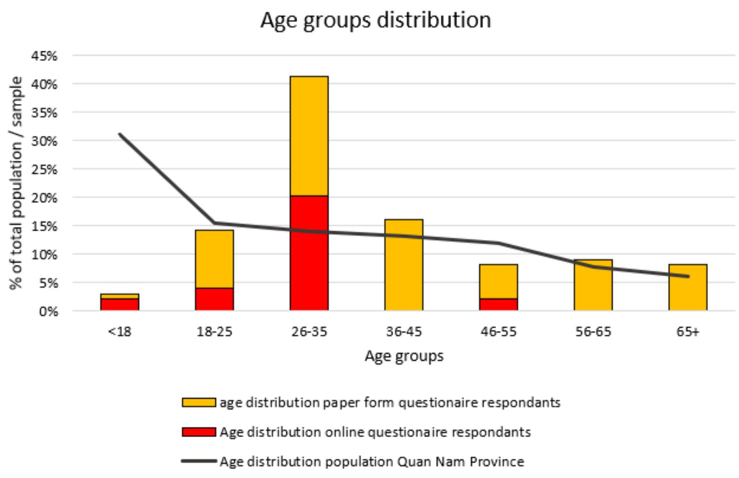


Figure 17: Age group distribution of the sample compared to actual age group distribution of Quan Nam Province. The figure shows shows that age group 25-36 is over-represented in the sample.

4.2.2.4 Sample size

Post Hoc ANOVA t-tests were conducted to check if the set goal of acquiring 50 to 100 participants for the survey (as described in appendix B.1.4.) was indeed a large enough sample to observe statistically significant differences of 0,5 point on the Likert scales between the means of multiple criteria. The analyses showed that for the whole dataset all the mean differences between criteria were significant if the mean values of the criteria differ more than 0,69 point on the Likert scale for the ES, and 0,61 for the EDS. It must be noted that due to the large number of comparisons made the family wise error rate correction (i.e., Bonferroni correction) is very strict, ($9{,}3 \times 10^{-4}$ for ES and $2{,}4 \times 10^{-3}$ for EDS) and therefore a lot of statistical power is lost. If the family wise error rate is not managed, the result show that the mean differences between all criteria were significant if the mean values between criteria differ more than 0,45 point on the Likert scale for the ES, and 0,44 for the EDS. These findings suggest that the sample size of 99 participants is indeed sufficient to observe statistically significant differences of 0,5 point on the Likert scales between the means of multiple criteria. The results of the post hoc ANOVA t-tests can be found in Appendix D.2.

4.2.3 Measure ranking

The measure ranking was performed by calculating the overall performance scores of all selected NBS. The calculations were conducted as described in the methodology chapter of this thesis (equation 4). The ranking of measures is shown in Figure 18. The measures are ranked based on their total normalized criteria scores, which consist of the total achieved ES scores (green), subtracted by the obtained cost (blue) and EDS scores (red)

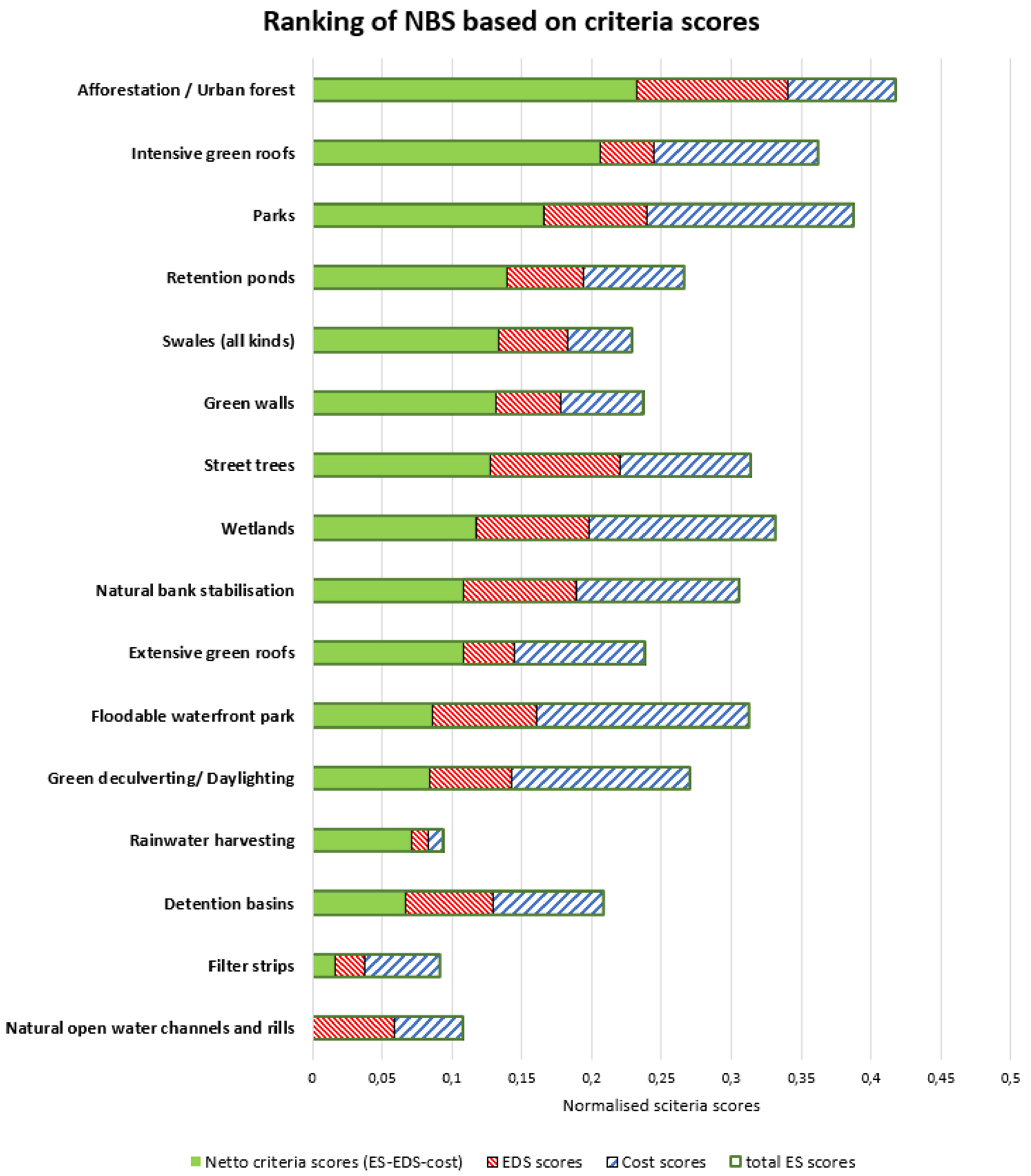


Figure 18: Obtained ranking of selected NBS for the case study area based on criteria scores. The measure ranking is based on the net achieved criteria scores (light green). This score is obtained by the total ES scores (dark green), subtracted by the cost (blue) and EDS scores (red).

Observing the obtained ranking, the NBS urban forest has the highest score, followed by intensive green roofs and parks. These measures are ranked highly due to their ability to provide a wide range of highly valued ecosystem services, such as reducing the urban heat island effect, improving air quality, and enhancing aesthetics (see Figure 14 and Table 17). Urban forest has the highest EDS score among all solutions but still ranks the highest. This is because urban forests provide the overall highest amount of ES among all measures and have lower construction and implementation costs compared to other solutions. Parks offer more ES than intensive green roofs but are ranked lower due to high land costs and the potential for more EDS compared to intensive green roofs. The NBS Natural open water channels and rills, rainwater harvesting, detention basins, and filter strips have obtained low scores. These measures are ranked relatively low because they are not able to provide a significant amount of ecosystem services.

In Table 18, the ranking is presented based solely on the consideration of ES. As mentioned earlier and evident from the table, urban forest would still rank highest, but the order of performance ranks would vary significantly among the other measures. If the measures were ranked solely based on total ES supply, wetlands would have obtained the 4th place. However, due to relatively high EDS and cost scores, it is ranked 8th. The same applies to street trees (7th), natural bank stabilization (9th), and floodable waterfront parks (11th), which all have relatively high EDS and cost scores compared to other solutions, resulting in lower rankings despite the ES they provide. On the other hand, retention ponds (4th), swales (5th), and green walls (6th) receive relatively high scores despite providing a limited amount of ecosystem services. This is primarily due to the relatively low costs of these solutions. This shows that by also including tradeoffs in terms of costs and EDS, a different ranking of measures emerges. This highlights the influence of varying costs and disservices per NBS on the decision-making process. Which allows for a more comprehensive and informed ranking to be achieved.

The table also provides insight into how the measure rank would have changed if only flood risk reduction was considered. NBS such as retention ponds, floodable waterfront parks and detention basins would have emerged as the top three measures considered, while in the main results they are ranked relatively low on 4th, 11th and 14th place due to relative moderate ES scores and high costs regarding floodable waterfront parks. This comparison shows that only considering flood risk reduction in the decision-making process may result in a suboptimal selection of measures in terms of costs efficiency and total potential benefits obtained from NBS.

Table 18: Change in the ranking of measures compared to the ranking shown in figure 18 if only ES or flood risk reduction is included as criteria for evaluation.

Selected NBS	Criteria Rank	Measure rank only ES considered	Measure rank only flood risk reduction considered
Afforestation / Urban forest	1	1	8
Intensive green roofs	2	3	6
Parks / urban trees	3	2	7
Retention ponds	4	9	2
swales (all kinds)	5	12	4
Green walls	6	11	15
street trees	7	5	10
Wetlands	8	4	12
natural bank stabilisation	9	7	9
Extensive green roofs	10	10	11
floodable waterfront park	11	6	1
Green deculverting/ Daylighting	12	8	5
Rainwater harvesting	13	15	14
Detention basins	14	13	3
Filter strips	15	16	16
Natural open water channels and rills	16	14	13

4.2.4 Sensitivity analysis

A sensitivity analysis was conducted by simulating the outcomes of the MCA with different criteria weights. This was achieved by running 5000 Monte Carlo simulations using different combinations of weights within the defined range limits (0-6) of the criteria and within one standard deviation as obtained from the survey results. The analysis was performed on the entire dataset, as the aim of this analysis is to test the stability and reliability of the model's results in general, rather than focusing solely on the NBS selected for the case study area.

When examining the results of the Monte Carlo simulations, where the weights are varied within their total range limits, the potential score ranges for all NBS are revealed. The overall criteria scores fluctuate between 0,53 and -0,26, depending on the measure. The score range and thus the sensitivity of the NBS vary significantly per measure. Parks demonstrate the highest sensitivity with a score range of 0,74, while filter strips exhibit the lowest sensitivity, with a score range of 0,19. NBS that receive scores on multiple criteria generally display higher sensitivity to changes in input, whereas NBS with few criteria scores are less sensitive. For instance, parks and wetlands have non-zero scores on 18 criteria, while rainwater harvesting only has 8.

From the analysis can be seen that the obtained scores from the citizens survey are relatively average in terms of potential scores when other weights would have been applied. Permeable pavements achieve the highest score regarding the potential score within their own range limit, reaching 68% of the maximum attainable score. Rainwater harvesting obtains the lowest score in this regard, with only 36% relative to the maximum attainable score.

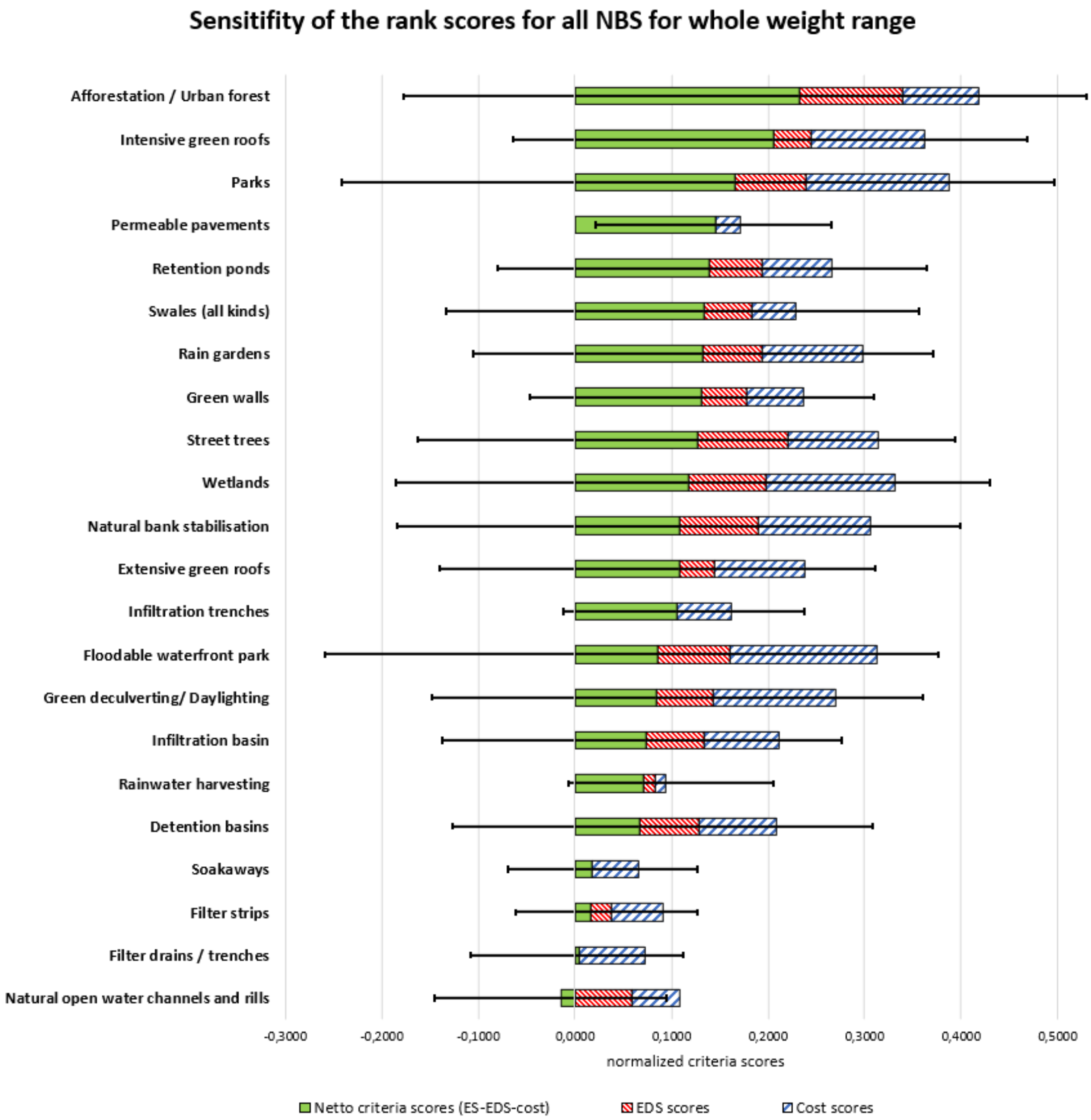


Figure 19: Rank score ranges of all measures after conducting 5000 Monte Carlo simulations varying the weights over their total range (0-6). The black bars indicate the potential range of rank scores that the measures can inhibit when different weighting is applied.

The results indicate that the application of different weights significantly impacts the final scores and therefore the ranking of measures. This underscores the importance of user-defined criteria weighting in this tool. Nevertheless, certain measures consistently receive low scores in terms of ES supply and exhibit limited sensitivity to different weight combinations. As a result, these measures consistently achieve very low rankings regardless of the weight configuration. Specifically, soakaways, filter drains, natural open water channels and rills, and filter strips consistently perform poorly in terms of ranking.

When examining the sensitivity of rank scores for all NBS while varying the weights within one standard deviation obtained from the surveys, it becomes apparent that the model exhibits relative uncertainty in terms of rank order due to data uncertainty. The measures in the top, middle, and low-ranking groups likely maintain their rank within their respective range groups, but the individual ranking within those groups can fluctuate with slight weight permutation's. This effect is particularly pronounced in the mid-ranking measures, as the net criteria scores obtained differ only slightly from one another. This sensitivity causes the ranking data to be less robust for data uncertainty induced in the weighting process.

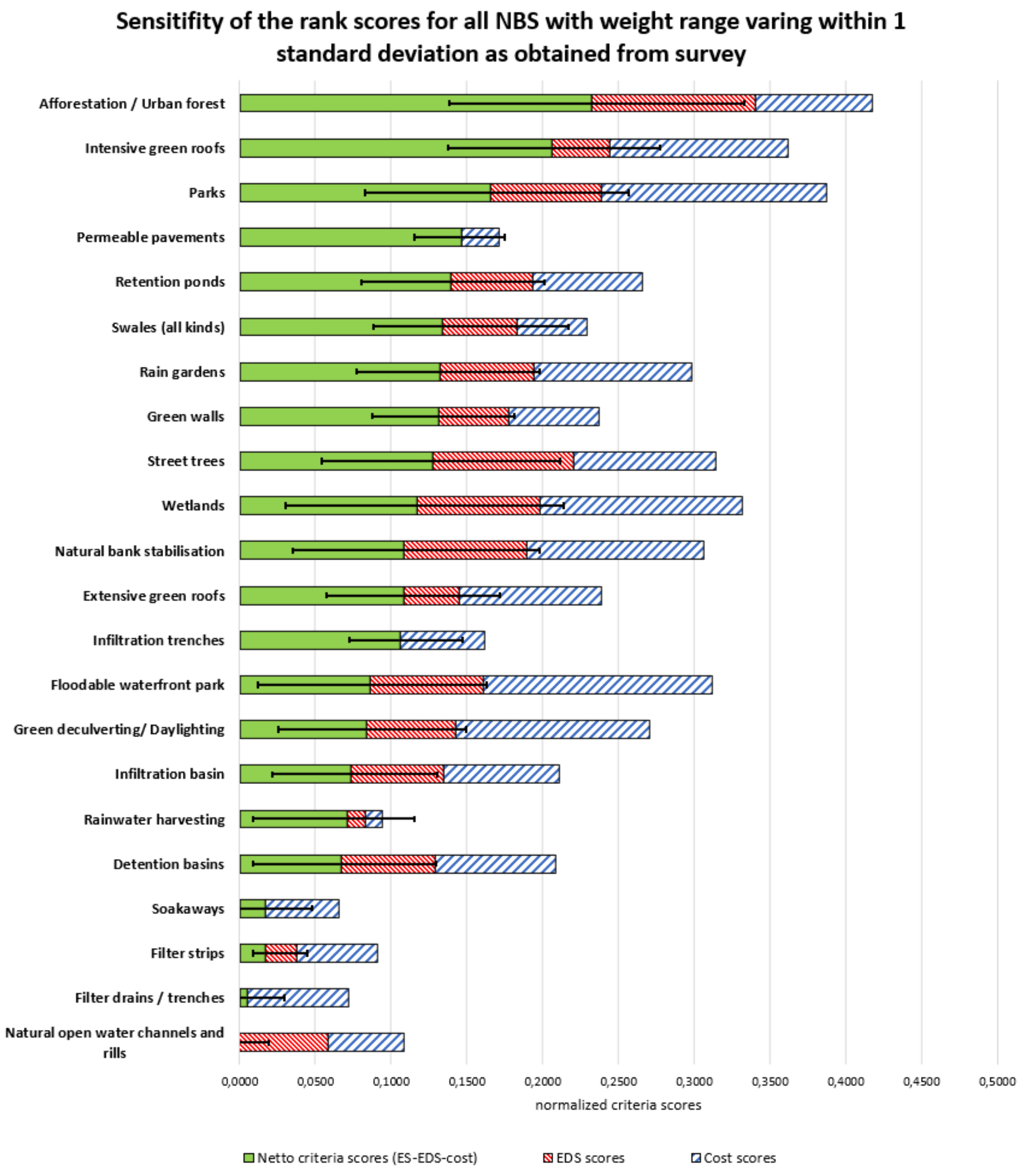


Figure 20: Rank score ranges of all measures after conducting 5000 Monte Carlo simulations, varying the weights within 1 standard deviation, as obtained from the survey. The black bars indicating the possible rank score range of measures reveal the relatively large uncertainty in terms of the total obtained score, and therefore, the potential rank order of measures.

5 Discussion & recommendations

The case study results demonstrate that the MCA tool can be used to holistically evaluate the performance of different NBS by assessing the benefits NBS provide in terms of ecosystem services, costs, and possible ecosystem disservices, and rank them accordingly to their individual performances. Nevertheless, it's clear that the current framework serves as a transitional product towards something truly optimized for practical use. Therefore, it's important to interpret the results, discuss the limitations and state recommendations on how to improve the current tool for future use. The discussed limitations and recommendations in this chapter are divided into four topics: (1) Participatory process, (2) Performance matrices, (3) Screening and ranking, (4) Transferability & practical applicability.

5.1 Participatory process

5.1.1 Interpretations data uncertainty participatory process

The sensitivity analysis showed that the tool is rather sensitive for changes in the weight input, which subsequently affects the final ranking of measures. Consequently, the large variation in ES / EDS perceptions among citizens increase data uncertainty and decreased the robustness the ranked NBS. It is therefore important to understand the possible causes of the large variation in ES / EDS perceptions among citizens to better understand how to integrate public participation in the decision-making process.

The high variation in answers can partly be explained by the personal nature of perceived criteria importance or the localized nature of problems. For instance, flood risk reduction exhibits the highest consensus regarding importance because flooding is widespread and has tangible negative consequences for Tam Ky. Therefore, people generally agree that decreasing flood risk is crucial. On the other hand, the three criteria with the highest variability in answers, namely pollen allergies, noise attenuation, and water capture and reuse, can be highly personal or local in nature.

For example, an individual with a pollen allergy would be extremely concerned about the increase of this disservice in the area, while those without allergies may not be affected and thus consider it as "not important." Similarly, individuals living in quiet areas or areas with stable water supply may perceive noise reduction or rainwater capture and reuse as "not important," whereas those living near busy roads or in areas with water supply issues may find these aspects extremely important to improve. This interpretation is supported by comments from citizens who mention selecting certain aspects as very important due to perceived local nuisances in their immediate living areas (see Appendix E.1). Nevertheless, no statistically significant spatial differences in ES or EDS perceptions among citizens could be found for locally perceived issues such as noise and air pollution near the industrial area.

Although not statistically confirmed, the comments of citizens (Appendix E.1.) suggest that citizens base their perceptions on their own local situations at and around their homes, rather than on the city scale. This suggestion is supported by other studies that work with ES or EDS perceptions, which indicate that perceptions of ES and EDS depend on individual local experiences (Lyytimäki & Sipilä, 2009; Gomez-Baggerthun and Barton, 2013; Buchel & Frantzeskaki, 2015; Miller & Montalto, 2019). Therefore, it is recommended to test the next application of this tool on the neighbourhood scale instead of the city scale. Selecting a more geographically limited area may increase consensus among citizens and generate a more robust recommendation in terms of NBS ranking for the target area. Furthermore, it is recommended for future use to clearly state at the beginning of the questionnaire what the exact target area for the implementation of new NBS is, and that citizens should base their perceptions on the general situation of the whole target area. This can be achieved, for example, by providing citizens with a map of the exact target area. These aspects are currently missing in the developed questionnaire and may result in lower consensus for certain criteria than necessary.

Another source of variability in ES and EDS valuation is due to demographics. For 11 out of 19 questions in the citizens' questionnaire, a negative correlation between age and ES/EDS valuation was found. This suggests that older individuals attribute a lower value to ES and EDS than younger individuals. This result differs from previous studies, where only relationships between perceived ES importance and education were found (Miller & Montalto, 2019; Ruiz-Frau et al., 2018). They suggested that the perceptions of the importance of ES are positively correlated with an individual's level of environmental knowledge and, therefore, education (Miller & Montalto, 2019; Ruiz-Frau et al., 2018).

No relation between education level and ES/EDS valuation was found in the current study, mainly because 40% of all respondents chose "prefer not to say" as an answer to this question. However, this does not completely rule out the possibility of a relation with education. Older individuals may have received their education during a time when environmental education was not as prominent or integrated into the curriculum. As a result, they may have had less exposure to the concepts and importance of ecosystem services compared to younger generations who have had more environmental education opportunities. Additionally, older people may have different priorities and values due to their age regarding safety and health. This may lead to a perceived lower emphasis on non-health and safety-related ecosystem services such as water capture and reuse and carbon sequestration, and a greater emphasis on more immediate health-related ES like flood risk reduction or heat reduction.

Above stated interpretations of the results show that the large variation in ES/EDS perceptions can partially not be prevented due to very personal priorities and values. It is therefore recommended that future tool users recruit a large enough sample size of at least 100 participants and carefully select their sample in terms of age and education to obtain a representative ES/EDS perception of the inhabitants in the target area. Additionally, the large variations in ES/EDS perceptions that have a local origin can potentially be decreased by selecting a more geographically limited area for future use.

5.1.2 Limitations participatory process

The output of the citizens' questionnaire demonstrated that citizens can successfully assess the importance of improving ES or express their concerns about EDS for their own city using a simple weighting technique using Likert scales (direct assignment weighting). This method was found to be straightforward and easy to understand for citizens, improving upon previously developed methods for capturing citizens' perceptions to obtain MCA weights. For example, the SWING weight elicitation method used by Aubert et al. (2020) was not well understood by laypersons, as only 12% of participants comprehended and complied with the process (Aubert et al., 2020). This highlights the feasibility of using a simple method like direct assignment weighting to obtain MCA weighting data from citizens, as opposed to more complex methods such as SWING weighting.

Nevertheless, there are some limitations to the method used for integrating public participation in the MCA framework. Firstly, the use of three different recruitment methods to acquire weighting data (online and paper version questionnaire and verbally for the cost criteria) may have influenced the valuation choices of participants. The different interfaces or settings may have affected how carefully participants considered their answers, potentially influencing the weighting output. However, the use of two different mediums for the questionnaire was considered beneficial as it allowed for acquiring more responses within a shorter time window by giving participants the option to choose the medium they preferred most.

Secondly, the survey may be prone to biases. Only one version of the questionnaire was created, which may introduce question order bias. Additionally, there is a possibility of framing bias in the survey. The way the questions are framed and explained can influence how respondents interpret the questions and, consequently, their chosen responses. Some questions may not have been well understood, may have had different meanings for different respondents, or may have been interpreted differently than intended by the researcher. These issues might have been amplified because the concepts and texts needed to be made understandable for laypersons and had to be translated into Vietnamese. However, the "face to face" surveying and a more guided approach for the older age groups may have reduced misunderstandings. Nevertheless, this approach was labour-intensive, reducing the efficiency and user-friendliness of the methodology.

Thirdly, stakeholders were involved in the process of defining the weights, but they were not involved in defining the criteria used in the analysis. The author made the decision to select the criteria, which can be seen as an arbitrary decision. To address this limitation, an additional step could have been included where stakeholders had the opportunity to select or regroup the criteria in a hierarchical structure that better aligns with their user requirements. This could have been achieved through the organization of a workshop involving local decision-makers and citizen representatives. Also, the importance weighting of the cost criteria was conducted by only three government officials. The low number of participants reduces the certainty of the obtained weights regarding cost. Again, this limitation could also have been improved by planning a workshop or group interview, allowing for more people to participate, supporting multidisciplinary discussions, and allowing for group consensus to be reached.

Finally, no systematic feedback on the too was communicated, hindering result validation and identification of areas for improvement.

5.2 Performance matrices

This research provides, to the best of the authors' knowledge, the first comprehensive performance matrices for a wide array of different NBS, ecosystem services, disservices, and corresponding costs. Due to data scarcity, different methods and data sources needed to be developed and combined to produce these matrices. This has provided limitations.

The ES scores were obtained by combining data from eight main sources, which in return are based on a total of 35 different sources like manuals, databases, and other papers. The strength of this method is that it allows to comprise a more elaborate dataset of different aspects of NBS performance. The unprocessed ES scoring matrix in Appendix A shows that selected papers assigned different scores to the same NBS on the same ES. By calculating the average score from the collected data, biases or errors from these sources are mitigated, enhancing the accuracy and reliability of the results. However, the combination of different sources also introduces assumptions that can increase data uncertainty in the scoring of NBS ES. Table 19 outlines three potential assumptions that may have contributed to scoring variations across these papers.

For scoring carbon sequestration and noise reduction, a distinct methodology was introduced, which links NBS to vegetation cover types. This approach offers the advantage of directly utilizing quantitative data on the performance of various vegetation types in reducing noise and sequestering carbon and converting them into scores. However, a limitation of this method is that the assigned vegetation cover types for the considered NBS rely solely on the author's expert judgment, which may introduce subjectivity. Additionally, the vegetation type classification used in the study only defines four types of vegetation, which is a simplified representation compared to the actual vegetation cover of NBS.

Table 19: Assumptions made to combine scoring data of ES on selected NBS. The right column provides an example of the assumption.

Assumptions made combining ES source materials.	**Example:**
Definition of solutions not strictly divined.	Permeable pavements exist in multiple forms, from porous bricks to open paving patterns filled with grass. The exact type may cause differences in ES supply, but the type considered is unspecified in most data sources. Therefore, the assumption was made all sources use the same definition.
Papers used for scoring use different names for ES and do not define their definition used.	The criteria ''ecological benefits'' used by Jia et al., 2013, ''habitat structure'' used by Ruangpan et al., 2021, and ''biodiversity'' used by Croesser et al., 2021 are all assumed to reflect the ES habitat for biodiversity.
Other sets of measures in papers cause other relative scoring between measures.	Urban forest score relatively best in terms of flood risk reduction for the list of green infrastructure, but average for a dataset where also SUDS like retention ponds are considered. Therefore only datasets assessing somewhat similar NBS where selected. Assumption was made that relative scoring between measures in selected dataset was similar enough to own dataset of measures.

A similar indirect scoring method based on vegetation cover was used for scoring the disbenefits. Therefore, the same limitations mentioned in the paragraph above apply to this scoring process. However, while the quantitative source data for noise attenuation and carbon sequestration from Dirkzen et al. (2015) was set for the urban environment, the scoring data from Campagne et al. (2018) was set for a national park in France. This difference in setting introduces the assumption that the scoring values for disbenefits in a sparsely populated natural area are the same as for the urban environment, which is very likely not the case. Considering the specific context of the urban environment and the lack of established direct relationships between individual NBS and possible disbenefits, the scored values may not accurately reflect reality for some cases.

Research on EDS related to NBS is extremely limited. Therefore, the EDS scores mainly rely on one data source, while the ES scores are based on eight main sources, which in turn are derived from a total of 35 different source materials such as manuals, databases, and other papers. As a result, the validity and reliability of the EDS scores are lower compared to the ES scoring. Thus, the EDS scores should be viewed as indicative rather than optimized for practical use at this point. To improve the EDS scores, further research is necessary to evaluate NBS disbenefits. Consistent with the existing literature, this research agrees that more studies on NBS disservices are necessary to adequately incorporate disservices into decision-making (Ommer et al., 2022.) Future tool users are encouraged to modify and enhance the default scoring when new research becomes available.

Above-mentioned issues reduce the data validity of the performance matrices are largely induced due to a lack of data. Although in recent years progress has been made to deliver databases on NBS benefits based on scoring systems (Castellar et al., 2021; NWRM, 2015; Naturvation, 2019), a comprehensive open-access database for direct quantitative data of individual NBS ES benefit performances does, as far aware of, not exist yet. Hence, it is recommended for future research to develop such a database. This would increase the evidence of the performances of specific NBS on specific aspects, improving the accuracy of performance matrices and hence NBS decision making, while also solidifying the business case of NBS in general.

5.3 Screening and ranking

A strength of current methodology is that it takes local site characteristics into consideration, therefore suggesting only locally relevant solutions for the area. This is an improvement compared to recently developed frameworks for NBS selection that do not incorporate this aspect, such as the frameworks from Croesser et al. (2021), and Ruangpan et al. (2020). Nevertheless, the current method neglects spatial heterogeneity, assuming the same site constraints for the entire case study area. This issue can be minimized by using a smaller study area for future uses, like the neighborhood scale. Also, to optimize this screening phase an extra screening criterion assessing spatial configuration of measures could be included. This criterion would check if the available space in the area is sufficient to accommodate large-scale NBS that require a minimum surface area for implementation, such as an urban forest or a retention pond.

As presented in the results, the tool seems to favor large-scale arboreal solutions, such as urban forests and parks, while consistently giving low ratings to small-scale NBS that mainly function as supporting components like filter strips. Similar results were obtained by Ruangpan et al. (2020) and Croesser et al. (2021). This effect is mainly caused by the ability of large-scale fully natural solutions to provide ecosystem services compared to small or unvegetated solutions. Hence, it is recommended for the design of future tools using ecosystem services for assessment to stratify the measure dataset. This could involve creating separate rankings for large-scale fully natural solutions and small-scale engineered components.

5.4 Transferability & practical applicability

The framework is aimed to be general, such that it can be used for cities worldwide. However, almost all data used in this work is based on studies from Europe or the USA. This observation is in line with the overall trend on NBS performance data, as only 15% of all studies related to NBS performance are from the global south (Chausson et al., 2020). The performance of NBS can differ based on differences in climate conditions (Gómez Martín et al., 2021). This might cause criteria scores to not accurately represent reality for some ES or EDS since the framework is tested for a city in Vietnam. NBS are, for example, found to be less effective in decreasing pluvial flooding during high-intensity events (Huang et al., 2020). Tam Ky experiences more high-intensity precipitation events than countries in Europe. Consequently, the relative performance of flood risk reduction compared to other ES such as recreation could be lower. This issue might reduce the transferability and accuracy of the scoring results for countries outside Europe and the USA, which is something to keep into consideration when using the tool. To reduce this bias and increase the transferability of the current framework (and all previously developed methods), more research on the NBS performance in countries in the global south, such as Vietnam, should be conducted.

Moreover, the developed tool was only tested on a single case study, Tam Ky. Therefore, the results cannot be validated and compared to different scenarios. To support the tool's further applicability and transferability, more applications are needed in terms of case study location and scale. Despite this being within the research objective, the strict time frame rendered it impractical.

The method provides a ranking of suitable measures, but not a defined final strategy of NBS implementation. To achieve this, the results should be communicated back to the involved stakeholders. As a next step, it is recommended to use the tool output as a basis for facilitating group discussions or workshops with the stakeholders, focusing on the organizational capabilities and siting of the top ranked NBS. By combining the output of current methodology with a spatial allocation method based on GIS based approaches such as the recently developed methods from Dirkzen et al. 2015, Saribi et al., 2022 or Longato et al., 2023 based on ecosystem service demand, or participatory map drawing, top ranked solutions can be sited during these workshops. Focusing on the organizational capability and siting of top ranked NBS allows to make a final decision on which configuration of measures should be selected for further analysis based on consensus within their local governance context (Raymond et al., 2017; Croesser et al., 2021; Albert el al., 2021). The impact of this developed scenario can further be assessed by employing more complex analyses such as detailed CBA or hydrodynamic modelling before arriving at a final decision (Alves et al., 2018, Albert al et., 2021).

To improve the practical usability in this tool to help facilitate scenario development during workshops with stakeholders, the methodology should be coded into software. Coding the tool into software allows for a more visually appealing and easy to navigate interface and automizes the process. The citizen questionnaire should also be coded into this application so that the data from filled-in questionnaires are automatically processed to derive weights. Future users of the tool are recommended to apply the tool on the neighborhood scale, sharing the questionnaire link through neighborhood-specific social media groups, email lists, or neighborhood association websites of the target area.

For the current case study, it was found that older residents value the benefits of NBS differently than younger generations and had a hard time engaging with the online format. It cannot be confirmed if this issue also applies to other study areas. Nevertheless, it is important for future users to be aware of this possible issue and make extra efforts to engage older citizens in the participatory process to successfully grasp the perceptions of all residents in the area. This may be achieved by providing printed copies that can be mailed or dropped off at community or senior centers and providing in-person support, for example, by organizing an information evening. Because this process cannot be digitized, it is more labor-intensive and time-consuming. Therefore, the current methodology may come with a trade-off between practical usability and successfully capturing the perceptions of all age groups for some study areas.

6 Conclusion

A novel methodology for the selection of suitable NBS for urban area's was developed to assist with the selection process making use of an ecosystem service approach. The obtained outcomes by implementing the framework on the case study area made it possible to successfully address both the main research question and two supporting research questions.

6.1 Answering the supporting questions

How can public perceptions of NBS benefits and disbenefits be integrated in the decision-making process, and how do these perceptions of the public impact the selection of measures?

The developed method to acquire weighting data from citizens was shown to be able to capture the perceptions of citizens on the importance of ecosystem services provided by NBS and possible disservices, identifying which are locally most relevant. Therefore, the method successfully incorporates public participation in the decision-making process. Adopting an ecosystem service approach using a Likert scale questionnaire has been demonstrated as an effective means of communicating the benefits and disbenefits of NBS towards citizens. The methodology was shown to be straightforward and easy to understand by citizens.

The case study results showed that citizens can be a valuable local resource for obtaining data to assess the importance of ES and EDS that can be provided by NBS. The case study results revealed that citizens perceive multiple ES as important and are also concerned about multiple EDS that could potentially be provided by NBS. This finding emphasizes the importance of focusing on the multiple benefits and negative effects of NBS in the decision-making process, as they might be highly valued by communities. By considering both the positive and negative impacts of NBS, decision-makers can gain a more holistic understanding of the importance of local ecosystem services and can help identify and address citizens' concerns related to potential adverse impacts. This enables decision-makers to align potential suitable NBS with the wishes and needs of the public. Understanding these wishes and needs may lead to better and more informed decisions on which NBS to implement that can provide the most local value, while minimizing negative consequences. In return, this can increase community acceptance of NBS and enhance NBS implementation.

The sensitivity analysis revealed that the tool is very sensitive to different weighting inputs. Consequently, the preferences of the public significantly impact the selection of measures, underscoring the importance of including citizens' preferences in the weighting process. On the other hand, this sensitivity also causes the ranking data to be less robust to data uncertainty induced in the weighting process. Therefore, it is crucial to minimize misunderstanding and misinterpretation in the weighting process to obtain a robust ranking of measures. This highlights the importance of equipping tool users with a straightforward and easily understandable weighting method, such as the direct weighting method employed in this study. Data uncertainty in the weights cannot be fully prevented due to very personal priorities and values of ES and EDS by citizens. Also, generational differences in terms of perceived importance of ES and EDS were found. It is therefore important to recruit a large sample, preferably around 100 participants, and carefully select the sample in terms of demographics to obtain representative criteria weights.

To what extent are different NBS able to supply ecosystem services and disservices?

By combining different data sources and methods, comprehensive performance matrices of a wide array of NBS could be constructed. The developed scoring matrices assess 11 ecosystem services and five ecosystem disservices. The results revealed significant variation among measures in terms of the extent to which NBS can provide ES and EDS. Generally, NBS perform best in improving aesthetics, and worst in improving provisioning services. Large scale fully natural solutions like wetlands, parks and urban forest were shown to be able to supply a large amount of ecosystem services, where small scale unvegetated solutions like channels and rainwater harvesting techniques scored poorly. Selected NBS were shown to be able to induce some EDS, but performance scores are low compared to the ES scores. The reliability of the EDS scores is low compared to the ES and cost scored due to a lack of research regarding EDS of NBS. Consequently, further research is necessary to evaluate the disservices associated with NBS.

6.2 Answering the main research question

How can an MCA tool be used to select suitable NBS for an urban area while integrating the ecosystem services concept and public participation in the decision-making processes?

The case study results showed that the framework can successfully be used to holistically evaluate the performance of different NBS and rank them accordingly to their individual performances. The tool incorporates a screening method that combines the NBS measure selector tool developed by IHE Delft with a site suitability assessment, considering general site characteristics to preselect locally relevant solutions. The method is followed up with an MCA tool which is based on 11 ecosystem services, five ecosystem disservices and three cost criteria. By combining different data sources and methods, comprehensive performance matrices of a wide array of NBS could be build. This is an improvement on previous works as discussed in the literature review, where only a few ES or benefits that flow from those ES are considered, and EDS are not assessed. Furthermore, this work advances NBS selection by making the process more participatory, integrating citizen perceptions into the weighting process.

The scoring and weighting data were integrated into a method that quantifies individual rank scores for preselected solutions and visually presents them in a ranking format. This ranking enables a holistic evaluation of NBS performances relative to each other, using a clear and multidisciplinary typology of the benefits and disadvantages associated with NBS. By also including costs and disservices in the MCA tool, a different ranking of measures emerges. This highlights the influence of varying costs and disservices per NBS on the decision-making process. Visually presenting the ranking by focusing on the multifunctionality and disadvantages of NBS can help decision-makers recognize the trade-offs of different NBS, providing a more complete assessment to help select locally relevant solutions accordingly.

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Appendix A. Development and results of performance matrices

A.1. Methodology and result for estimating the capacity of different NBS to provide the ES noise reduction and carbon sequestration.

No direct scoring data on the ES noise attenuation and carbon sequestration could be found. To assign scores for noise reduction and carbon uptake of the selected NBS, quantitative data based on vegetation types was used from Dirkzen et al. (2015). In the paper by Dirkzen et al., six different ecosystem services supplied by urban green spaces are quantified and mapped based on high-resolution cadastral vegetation type data at the scale of individual trees and shrubs for the city of Rotterdam, the Netherlands. The ecosystem service delivery capacity of the six ES was derived per vegetation type per square meter from a literature study of previous works on vegetation types (Dirkzen et al., 2015).

To derive ES scores from 0 to 5, first, all NBS were categorized based on the assumed land cover types that each NBS consists of, as determined by the expert judgment of the researcher. The land cover type classification is the same as used in the paper by Dirkzen et al. (2015), which includes woodland, tall shrubs, short shrubs, herbaceous vegetation, and water. NBS can consist of a combination of different vegetation types. Therefore, some solutions were categorized as a mixture of different vegetation types (e.g., parks, assumed to have a mix of woodland, tall and short shrubs, and herbaceous vegetation). The assigned mixed vegetation types were expressed and weighted as a percentage distribution for the respective NBS. Next, these vegetation distributions were multiplied by the carbon uptake values and noise reduction values per vegetation type in square meters, as obtained from Derkzen et al. (2015) (equation 5).

$$x_{nbs} = (lc_1 * v_1) + (lc_2 * v_2) + (lc_3 * v_3) + \ \ldots \quad (eq.5)$$

> *x_{nbs} = quantitative amount of noise reduction or carbon uptake per NBS in m^2*
>
> *lc_n = land cover type in terms of fraction of the total area, where the total land cover adds up to 100%*
>
> *v_n = quantitative value in m^2 corresponding to relevant land cover type.*

Next, the calculated values were normalized (equation 6), where the upper range limit was determined by the highest possible amount of noise reduction or carbon uptake in terms of land cover counts. Afterwards, all NBS were scored from 0 to 5 based on the corresponding normalized interval value ranges in which the normalized calculated ES value falls, as shown in Table 21. This process resulted in scoring both noise reduction and carbon uptake.

It was assumed that water bodies and paved surfaces are not capable of reducing noise levels in the area, and paved surfaces are not capable of sequestering carbon. Therefore, NBS that do not contain any vegetation were assigned a score of zero for both carbon uptake and noise reduction.

The work of Derkzen et al. was focused on quantifying the supply rate of ES of urban green. Because of this, waterbodies where not assigned with a value for both carbon uptake and noise reduction. Water bodies do not provide any noise reduction. But they do provide carbon uptake. For both water body types (wetland and retention pond), values for carbon uptake in kg/m2/year were searched in literature. For retention ponds, a carbon storage value of 0.135 kg/m2/year was derived from the work of Merriman et al., 2017. For wetlands, a mean value of 7,2 kg/m2/ year was derived from the work of Dong et al., 2012. This resulted in a relative scoring of 1 and 3 for both solutions respectively.

Urban vegetation type	Carbon storage (kg/m^2)	Noise reduction ($dB(A)/100\ m^2$)
Single tree	10,64	-
Woodland	15,62	1,125
Tall shrub	7,79	2,0
Short shrub	5,61	1,125
Herbaceous	0,17	0,375
Water:		
Retention pond*	0,135	-
Wetland**	7,2	-

*Table 20: Quantitative carbon storage and noise reduction values derived from Dirkzen et al., 2015 used to calculate performance scores. *Derived from Merriman et al., (2017). ** derived from Dong et al., (2012).*

Qualitative value	Range intervals normalized index values (I_{nc})	Score
None	0	0
Very low	0,01-0,20	1
Low	0,21-0,40	2
medium	0,41-0,60	3
High	0,61-0,80	4
Very high	0,81-1,00	5

Table 21: Normalized index range intervals and corresponding scores.

$$I_{nc} = \frac{x_{nc}}{Max(x_c)} \quad (eq. 6)$$

I_{nc} = normalized assessment index for NBS *n* and criteria *c*

x_{nc} = quantitative value for NBS *n* and criteria *c*

$Max(x_c)$ = maximum quantitative value found of all NBS in criteria c

Table 22: Assumed vegetation typology per selected NBS and calculated scores.

Selected measures	Assumed vegetation types / topology	Noise attenuation			Carebon sequestation		
		noise attenuation levels (Dba / 100 m2)	normalised score	Bucket score	Carbon uptake (kg /m2/year)	normalised score	Bucket score
Retention ponds	no vegetation	0,000	0	0	0,135	0,00864277	1
Rainwater harvesting	no vegetation	0,000	0	0	0	0	0
Detention basins	herbaceous	0,375	0,1875	1	0,17	0,01088348	1
Natural open water channels and rills	water	0,000	0	0	0	0	0
swales	herbaceous	0,375	0,1875	1	0,17	0,01088348	1
Extensive green roofs	herbaceous	0,375	0,1875	1	0,17	0,01088348	1
Intensive green roofs	tall shrub 25%, short shrub 75%	0,891	0,4453125	3	6,705	0,42925736	3
Artificial wetlands	water 50%, short shrub 50%	0,563	0,28125	2	7,2	0,4609475	3
Green walls	75% short shrub, 25% tall shrub	1,344	0,671875	4	6,1625	0,39452625	2
Parks	tall shrub 15%, short shrub 15% herbaceous 45% woodland 25%	0,919	0,459375	3	5,993	0,38367478	2
Greening waterfronts / floodable park	tall shrub 15%, short shrub 15% herbaceous 45% woodland 25%	0,919	0,459375	3	5,993	0,38367478	2
Street trees/green streetscape	woodland 50%, herbacious 50%	0,750	0,375	2	10,64	0,68117798	4
natural bank renaturalisation	short shrub 25%, herbaceous 75%	0,563	0,28125	2	1,5325	0,0981114	1
stream daylighting	water 75% short shrub 25%	0,281	0,140625	1	1,405	0,08994878	1
Afforestation	woodland 100%	1,125	0,5625	3	15,62	1	5
Filter strips	herbaceous	0,375	0,1875	1	0,17	0,01088348	1
Not selected measures							
Permeable pavements	no vegetation	0,000	0	0	0	0	0
Soakaways	no vegetation	0,000	0	0	0	0	0
Infiltration basin	herbaceous	0,375	0,1875	1	0,17	0,01088348	1
Rain gardens	short shrub 25%, herbaceous 75%	0,563	0,28125	2	1,5325	0,0981114	1
Infiltration / filter trenches	no vegetation	0,000	0	0	0	0	0
filter drains	no vegetation	0,000	0	0	0	0	0

A.2. Methodology and results for estimating the capacity of different NBS to induce an EDS

After intensive literature search, no sources could be found that previously directly scored EDS of NBS. As a result, an indirect scoring method was utilized. The quantitative scoring of ES and EDS was based on vegetation types from the paper by Campagne et al. (2018). In their study, the researchers scored six different EDS associated with various vegetation types in a national park in France. They employed an expert judgment approach, where scores were assigned on the same 0-5 scoring system used for ES scoring in this study. A panel of 17 experts, consisting of individuals with expertise in ES and/or ecology, heads of territorial organizations, project or site managers, or engineers working in environmental or ecological fields (Campagne et al., 2018), were asked to fill in the vegetation type/EDS matrices based on their best knowledge estimates (Campagne et al., 2018). The mean values from this survey on EDS were used as the data to fill in the EDS performance matrix.

If more specific research on EDS induced by NBS could be found, the available data was utilized. However, it should be noted that this data was quite limited. Only regarding the EDS caused by disease vectors carried by animals, it was discovered that urban green roofs have no effect on increasing the abundance of disease vectors due to high wind exposure on roofs (Wong & Jim, 2017). As a result, a score of zero was assigned.

EDS values per NBS were assigned based on their corresponding land cover types as classified in the work of Campagne et al. (2018). The assignment of vegetation types was determined by the expert judgment of the researcher. For example, the NBS filter strips and swales were assigned the land cover type "grass strips," and street trees were assigned the land cover type "hedgerows, tree alignments." In cases where an NBS type is characterized by a mix of land covers (e.g., stream daylighting, assumed to have a mix of water's edge vegetation and running water), the EDS values were weighted based on the assumed percentage shares of the NBS area occupied by each land cover, following the same approach as stated in Equation 5. The obtained EDS scores, rounded to two decimal places, are shown in Table 23.

No scoring data on the cultural disservice "aesthetical issues" could be found. Therefore, these scores were estimated based on expert judgment using indicator proxies: view blockage potential and unilluminated area & level of extensive management of the solution (Doran & Haase, 2015; Gómez-Baggethun et al., 2013). For both indicators, three questions per indicator were developed to score the aesthetical disbenefits by assigning 1 point per question if the answer is "yes" (see Table 24). The total overall score was obtained by calculating the average score of the assigned scores for both indicators. As a result, no scores higher than 3 (indicating a medium negative effect) could be assigned. The expert-based survey scores for the other EDS from Campagne et al. (2018) all fall within the value range between 0 and 3. To maintain a conservative qualitative estimate, it was decided to keep the scores for the aesthetical issues disservice within this value range as well.

Table 23: Assigned scores for EDS based on vegetation types as assessed by Campagne et al., 2018. per selected NBS.

measure	Land cover type	Habitat competition with humans	Allergies	Decease transmition	Infrastructure Damage	Aestetical issues
Retention ponds	Bottom or shores of unvegetated water body's	1,90	0,19	1,90	0,67	0,5
Rainwater harvesting	fresh water	-	-	2,50	-	0
Detention basins	Grass strips	1,75	2,40	1,70	0,13	1
Natural open water channels and rills	25% Water's edge vegetation, 75% running water	1,58	1,58	1,55	1,05	0,5
Swales	Railway and roadside fallows	1,31	1,75	1,19	0,8	0,5
Extensive green roofs	urban ecosystem (general)	1,25	1,55	1,11	0,72	1
Intensive green roofs	crops	1,06	1,44	1,00	0,33	0,5
Artificial wetlands	Water's edge vegetation	2,40	2,40	2,25	0,27	1,5
Green walls	urban ecosystem (general)	1,25	1,55	1,11	0,72	0,5
parks	Urban parks and large gardens	1,53	3,06	1,25	0,87	2
Greening waterfronts / floodable park	90% Urban parks and large gardens, 10% water edge vegetation	1,62	2,99	1,35	0,81	2
street trees	Hedgerows / tree alignments	2,40	2,70	2,10	1,10	2
natural bank stabilisation	Water's edge vegetation	2,40	2,40	2,25	0,27	1,5
Stream daylighting	25% Water's edge vegetation, 75% running water	1,58	1,58	1,55	1,05	0,5
Afforestation / Urban forest	Deciduous Forests	2,90	2,80	2,60	0,93	2,5
Filter strips	Rail and roadside networks	0,56	0,75	0,38	0,67	0
Not selected measures						
Permeable pavements	-	-	-	-	-	0
Soakaways	-	-	-	-	-	0
Infiltration basin	Grass strips	1,75	2,40	1,70	0,13	1
Rain gardens	Urban parks and large gardens	1,53	3,06	1,25	0,87	0,5
Infiltration trenches	-	-	-	-	-	0
filter treches /drains	-	-	-	-	-	0

Table 24: Questions per indicator to score the aesthetical disbenefits by assigning 1 point per question if the answer is yes, the total score is obtained by the number of points obtained through the number of indicators (n=2)

Indicators	Questions regarding measure	Assign 1 point if yes
unilluminated area & level of extensive management	Does the vegetation of the NBS has the potential to be extensively managed?	
	Is the vegetation of the NBS per default extensively managed?	
	Does the NBS contains a large area (>100m^2) that cannot be luminated?	
View blockage	Is the vegetation of the NBS higher than 2m?	
	Is the vegetation of the NBS higher than 2m and often near windows?	
	Is the vegetation higher than 2m and often near roads?	
Overall score		= total point column / number of indicators

A.3. Raw scoring data, cost scores calculations and general normalized and 0 – 5 score matrices

In the next pages, the unprocessed scoring data, cost scores calculations and general normalized and 0 – 5 score matrices are shown for all measures considered, not selected measures included. Table 26 shows the data origin for scoring the ES, table 25 shown the legenda that indicates which color each source means. Table 27 shown the cost range results and corresponding score calculations. Table 28 shows all unrounded obtained normalized scores of all considered criteria and table 29 and 30 show the general 0-5 scores performance matrices for all NBS addressing pluvial flooding considered in the RECONECT database.

Table 25: Color legenda of scores indicating the data origins of the scores used to score all ES.

Literature providing scoring data ES matrix	Origin sources papers used for scoring their work
Ruangpan et al., 2021	Woods Ballard et al.2007; Klijn et al. 2013; CIRIA 2014; The River Restoration Centre 2014; NWRM 2015; Woods Ballard et al. 2015; WRT 2016; Alves et al. 2018a; Bilodeau et al. 2018; Van Coppenolle et al. 2018; Leonardo Mantilla Nino, 2019, Watkin et al. 2019; UnaLab 2020
Alves et al., 2018	Shoemaker et al., 2009; Center for Neighborhood Technology, 2010; UDFCD, 2010; CIRIA, 2013; Jia et al., 2013; DEFRA, 2016
Croesser et al., 2021	Survey among 24 NBS experts rating solutions
Jia et al., 2013	Expert judgement author
Sarabi et al., 2022	Alves et al.,2018; DEFRA, 2020; NWRM, 2020
Castellar et al., 2021	RBANGreenUP, 2018; UNALAB, 2019; NATURE4CITIES 2020 Somarakis et al., 2019; Hemming et al.(2018); European Commission, 2015; Cohen-Shachametal.,2016; Langergraber et al., 2020
Dirkzen et al., 2021	Fang & Ling (2003), Bolund & Hunhammar (1999); Chaparro & Terradas (2009); Davies et al. (2011); Nowak et al. (2013); Raciti et al. (2012); Strohbach & Haase (2012); Zhao et al. (2010)
Factsheets NWRM., 2015	Woods Ballard et al., 2007; Atkins et al., 2010; CIRIA 2009; Abirached & Faby, 2008; Environmental agency 2012; CREW 2012
No data found, expert judgement author	

Table 26: Scores found in literature for the ES criteria, colors indicate the literature origin of the data. For the legenda see previous page.

Selected measures	flood risk reduction	groundwater recharge	water quality improvement	air quality improvement	Carbon sequestration	noise attenuation	urban temperature regulation	habitat for biodiversity	recreation and aminity	Aestetics	water capture and reuse	production of market goods
Retention ponds	4 5 5 4	0 2	2 4 3	2 3 0 0	1	0	2 4 2 1	4 3.5 3 3	3 3 0	4 3 2	5 5 0	3 0
Rainwater harvesting	2	0 0	1	0	0	0	1	0 0	0	0 1	5 5	0
Detention basins	4 5	2 2	1	0 0	1	1	1 2	2 1	3 3	3 1	3 4	1
Natural open water channels and rills	2	0	0	1	0	0	1	2	0	2	0	0
swales (all kinds)	3 5 4 4	2 2	2 4 4	2 2 2 1,5	1	1	3 4 2 0,5	3 3,5 2 3	1 2 0	2 3 3	1 1 0	0 0
Extensive green roofs	3 2.5 2 2	0 0	2 2.5 2	3 2.5 3 3.5	1	1	3 4 3 4	2 2.5 4 1	2 2 3	3 4 4.5	0 1 2	0 0
Intensive green roofs	3 3.5 4 3	0 0	3 3.5 2.5	4 3 5 4	3	2	4 4 4 5	3 4 4 1.5	2 5	4 4 5	0 1 3	5 0
Wetlands	4 2 1	0	3 3.5 5	2 0	3	2	2.5 3	4 3 5 5	4 3	5 5	5	1
Green walls	2 2 0	0	2 2 0	3 3,5	2	4	3 4.5	1 2.5 4	0 0	5	0 0	0
Parks / urban trees	2 4 3.5	2	4 4.5 3	5 5	3	3	5 4.5	3 4 4	5	5	0	1
floodable waterfront park	5 5 4.5	2	2 3 1.5	3 2	3	3	3 1	2 3.5 3	4 5	4,5	0 0	0
street trees	2 4 2 3	2	2 4.5 0	5 5 4,5	4	2	5 5 4.5	2 4 2	0 3 2	4	0	1
natural bank stabilisation	3 3 2.5	0	4 4 3.5	3 1	2	2	4 1.5	3 4 4	3 5	3,5	5	0
Green deculverting/ Daylighting	3 4	2	2 3.5	1	1	1	2,5	3 4.5	3 3.5	3,5	2	2
Afforestation / Urban forest	2 4.5 2.5	4	4 4.5 3.5	5 4.5	5	3	5 5	5 5 3	2 5	5	0	2
Filter strips	1	2	2	0	1	1	1	1 2	0	1	1	0
not selected measures												
Permeable pavements	3 3 4 4	4 3	2 4 5 3	0 2 0 0	0	0	3 2 1 0,5	0 1 1,5 2	0 1 3	2 2 1	2 2 0	0 0
soakaways	3	4	1	0	0	0	0	0	0	0	1	0
infiltration basin	4 5 3,5	5	1 1	0 2	1	1	2 0,5	2 1 3	3 3 5	1 4	3 0	0
rain gardens	3 4 4 4	4 1	2 4 4 4	2 2 0 2,5	2	2	3 3 1 3	3 4 3 3,5	3 1 0 1	5 3	1 5	2 0
infiltration trenches	2	4	2 5	2	0	0	2	0 1 1	0 1	1 3	2 2	0
filter drains / trenches	2	2	2	0	0	0	0	0 0	0	1	1	0

Table 27: Level of land acquisition and cost ranges of NBS considered in MCA as found in literature. The mean value of the cost range is taken to calculate the normalized scores.

Selected Measures	capital cost							operation and maintenance costs (m^2/year)					sources
	Land costs		construction costs (m^2)										
	low/mid/high	score 0 - 5	Min $	Max $	Mean $	normalised score	score 0 - 5	Min $	Max $	Mean $	normalised score	score 0 - 5	**NWRM factsheets (2015)
Retention ponds	**high**	**4,0**	10,0	60,0	35,0	**0,13**	**1**	1,0	5,0	3,0	**0,1**	**1**	NWRM factsheets (2015)
Rainwater harvesting	**ver low**	**0,0**	5,0	60,0	32,5	**0,13**	**1**	0,3	1,0	0,6	**0,02**	**1**	NWRM factsheets (2015)
Detention basins	**high**	**4,0**	10,0	110,0	60,0	**0,23**	**2**	0,5	5,0	2,8	**0,09**	**1**	NWRM factsheets (2015)
Natural open water channels and rills	**very low**	**1,0**	59,0	100,0	79,5	**0,31**	**2**	-	-	very low	-	**1**	Aerts et al., (2018 Zhou et al., (2013) maintenance cost not quantified, only range, sources: Susdrain.org, NWRM factsheets (2015)
Swales	**med**	**3,0**	15,0	80,0	47,5	**0,18**	**1**	0,5	4,0	2,3	**0,07**	**1**	NWRM factsheets (2015)
Extensive green roofs	**none**	**0,0**	25,0	225,0	125,0	**0,48**	**3**	3,5	55,0	29,3	**0,94**	**5**	NWRM factsheets (2015) Iwaszuk et al. (2019)
Intensive green roofs	**none**	**0,0**	130,0	300,0	215,0	**0,83**	**5**	0,5	55,0	27,8	**0,9**	**5**	NWRM factsheets (2015) Iwaszuk et al., (2019)
Wetland	**very high**	**5,0**	20,0	230,0	125,0	**0,48**	**3**	1,2	26,0	13,6	**0,44**	**3**	Aerts et al. (2018) Jia et al. (2013)
Green walls	**none**	**0,0**	157,0	215,0	186,0	**0,72**	**4**	2,8	2,8	2,8	**0,09**	**1**	Perini & Rosasco, (2013)
Parks	**very high**	**5,0**	120,0	400,0	260,0	**1,00**	**5**	0,3	2,7	1,5	**0,05**	**1**	Tempesta (2014) *Holden, (2007) *Medium expensive parks considered
Floodable waterfront parks	**very high**	**5,0**	120,0	400,0	260,0	**1,00**	**5**	1,0	5,0	3,0	**0,1**	**1**	https://nrcsolutions.org/waterfront-parks/ *Holden, (2007) *Medium expensive parks considered
Street trees/green streetscape (*per tree)	**none**	**0,0**	26,0	200,0	113,0	**0,43**	**3**	27,0	35,0	31,0	**1,0**	**5**	Chen et al., (2021) Moore (2021)
natural bank stabilisation	**low**	**2,0**	85,0	140,0	112,5	**0,43**	**3**	5,7	51,3	28,5	**0,92**	**5**	Baird et al., (2015)

Stream daylighting	**low**	**2,0**	-	-	very high	**-**	**5**	-	-	low	-	**2**	*EPA (2021) *https://nrcsolutions.org/daylighting-rivers/ *Not quantified in m^2 due to extreme varying estimates due to local site characteristics and channel width.
Afforestation / Urban forest	**very high**	**5,0**	1,9	44,0	22,9	**0,09**	**1**	0,2	0,6	0,4	**0,01**	**1**	Holden (2007) Kuser (2007) Forbes (2021) Worldbank (2021)
Filter strips	**medium**	**3,0**	3,0	30,0	16,5	**0,06**	**1**	0,5	6,5	3,5	**0,11**	**1**	NWRM factsheets (2015)
not selected measures	**low/mid/high**	**score 0 - 5**	**min**	**max**	**mean**	**normalised score**	**score 0 - 5**	**min**	**max**	**mean**	**normalised score**	**score 0 - 5**	
soakaways	**very low**	**1,0**	90	140	115,0	**0,44**	**3**	0,25	1,25	0,8	**0,02**	**1**	NWRM factsheets (2015)
infiltration basin	**high**	**4,0**	15	90	52,5	**0,20**	**2**	0,15	5,5	2,8	**0,09**	**1**	NWRM factsheets (2015)
rain gardens	**low**	**2,0**	0	500	250,0	**0,96**	**5**	0	4	2,0	**0,06**	**1**	Susdrain.org Worldbank, (2021**)**
infiltration trenches	**low**	**2,0**	70	90	80,0	**0,31**	**2**	0,25	4	2,1	**0,07**	**1**	NWRM factsheets (2015)
Permeable pavements	**none**	**0,0**	40,0	90,0	65,0	**0,25**	**2**	1,0	5,0	3,0	**0,1**	**1**	NWRM factsheets (2015)
Filter trenches /drains French drains	**very low**	**1,0**	33,0	165,0	99,0	**0,38**	**2**	-	-	low	-	**2**	https://www.bobvila.com/articles/french-drain-cost/ https://lawnlove.com/blog/french-drain-cost/ https://www.bobvila.com/articles/french-drain-cleaning/

***Key references NWRM factsheets: www.uksuds.org- SuDS Construction and Maintenance Costs Calculator, Chocat &Faby (2008), Environment Agency (2012), Woods-Ballard et al., 2007, Atkins (2010), CREW (2012), CIRIA (2009), Environment Agency (2012)*

Table 28: Normalized unrounded scores for all criteria and measures.

Selected measures	Ecosystem services											Ecosystem disservices					Cost		
	Flood risk reduction	Water quality improvement	Air quality improvement	Carbon sequestration	Noise attenuation	Urban temperature regulation	Habitat for biodiversity	Recreation and aminity	Aestetics	Water capture and reuse	Production of market goods	Habitat competition with humans	Allergies	Decease transmition	Infrastructure Damage	Aestetical issues	Land aquisition	Construction cost	Maintenacne cost
Retention ponds	0,90	0,60	0,25	0,01	0,01	0,45	0,68	0,40	0,60	0,67	0,30	0,38	0,04	0,38	0,13	0,10	0,80	0,13	0,10
Rainwater harvesting	0,40	0,20	0,00	0,00	0,00	0,20	0,00	0,00	0,10	1,00	0,00	0,00	0,00	0,50	0,00	0,00	0,20	0,13	0,02
Detention basins	0,90	0,20	0,00	0,19	0,01	0,30	0,30	0,60	0,40	0,70	0,20	0,35	0,48	0,34	0,03	0,20	0,80	0,23	0,09
Natural open water channels and rills	0,40	0,00	0,20	0,00	0,00	0,20	0,40	0,00	0,40	0,00	0,00	0,32	0,32	0,31	0,21	0,00	0,20	0,31	0,20
swales (all kinds)	0,80	0,67	0,38	0,19	0,01	0,48	0,58	0,20	0,53	0,13	0,00	0,26	0,35	0,24	0,16	0,10	0,40	0,18	0,07
Extensive green roofs	0,48	0,43	0,60	0,19	0,01	0,70	0,48	0,47	0,77	0,20	0,00	0,25	0,31	0,00	0,14	0,20	0,00	0,48	0,94
Intensive green roofs	0,68	0,60	0,80	0,46	0,43	0,85	0,66	0,70	0,87	0,27	0,50	0,21	0,29	0,20	0,07	0,10	0,00	0,83	0,90
Wetlands	0,47	0,77	0,20	0,28	0,46	0,55	0,85	0,70	1,00	1,00	0,20	0,48	0,48	0,45	0,05	0,30	1,00	0,48	0,44
Green walls	0,27	0,27	0,65	0,67	0,39	0,75	0,50	0,00	1,00	0,00	0,00	0,25	0,31	0,22	0,14	0,10	0,00	0,72	0,09
Parks / urban trees	0,63	0,77	1,00	0,46	0,38	0,95	0,70	1,00	1,00	0,00	0,20	0,31	0,61	0,25	0,17	0,40	1,00	1,00	0,05
floodable waterfront park	0,83	0,43	0,50	0,46	0,38	0,40	0,57	0,90	0,90	0,00	0,00	0,32	0,60	0,27	0,16	0,40	1,00	1,00	0,10
street trees	0,55	0,43	0,97	0,38	0,68	0,97	0,53	0,33	0,80	0,00	0,20	0,48	0,54	0,42	0,42	0,40	0,20	0,43	1,00
natural bank stabilisation	0,57	0,77	0,40	0,28	0,01	0,55	0,73	0,80	0,70	1,00	0,00	0,48	0,48	0,45	0,05	0,30	0,40	0,43	0,92
Green deculverting/ Daylighting	0,70	0,55	0,20	0,14	0,01	0,50	0,75	0,65	0,70	0,40	0,40	0,32	0,32	0,31	0,21	0,10	0,40	1,00	0,40
Afforestation / Urban forest	0,60	0,80	0,95	0,56	1,00	1,00	0,87	0,70	1,00	0,00	0,40	0,58	0,56	0,52	0,19	0,50	1,00	0,09	0,01
Filter strips	0,20	0,40	0,00	0,19	0,01	0,20	0,30	0,00	0,20	0,20	0,00	0,11	0,15	0,15	0,13	0,00	0,60	0,06	0,11
Not selected measures																			
Permeable pavements	0,70	0,70	0,10	0,00	0,00	0,33	0,23	0,27	0,33	0,27	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,10
soakaways	0,60	0,20	0,00	0,19	0,01	0,00	0,00	0,00	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,44	0,02
infiltration basin	0,83	0,20	0,20	0,28	0,01	0,25	0,40	0,73	0,50	0,30	0,00	0,31	0,61	0,25	0,17	0,10	0,80	0,20	0,09
rain gardens	0,75	0,70	0,33	0,40	0,40	0,50	0,68	0,25	0,80	0,60	0,20	0,35	0,48	0,34	0,03	0,20	0,40	0,96	0,06
infiltration trenches	0,40	0,70	0,40	0,00	0,00	0,40	0,13	0,10	0,40	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,40	0,31	0,07
filter drains / trenches	0,40	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,38	0,40

Table 30: General performance matrix of ES criteria for all NBS.

Selected measures	Short discription of solution	Ecosystem services											Total ES points measure
		Regulating services						Supporting services	Cultural services		Provisioning services		
		Flood risk reduction	Water purification	Air purification	Carbon sequestration	Noise attenuation	Urban heat island mitigation	Habitat for biodiversity	Recreation	Aestetics	Water capture and reuse	Production of market goods	
Retention ponds	Pond designed with extra storage capacity to collect and hold stormwater runoff.	5	3	1	1	0	2	3	2	3	3	2	25
Rainwater harvesting	Collection and storage of rain from roofs in barrels or tanks.	2	1	0	0	0	1	0	0	1	5	0	10
Detention basins	Dry surface storage basin that can inudate during storm events.	5	1	0	1	1	2	2	3	2	4	1	22
Natural open water channels and rills	Shallow open surface water channels with hard edges to convey stormwater.	2	0	1	0	0	1	2	0	2	0	0	8
Swales (all kinds)	Shallow, linear channels vegetated with grass or shrubs to convey, absorb and slow down stormwater.	4	3	2	1	1	3	3	1	3	1	0	22
Extensive green roofs	Green roof with a thin substrate layer covered with herbaceous vegetation and mosses.	2	2	3	1	1	3	2	2	4	1	0	21
Intensive green roofs	Green roof with a deep substrate layer allowing to grow gardens on rooftops.	3	3	4	3	2	4	3	3	4	1	3	33
Wetlands	Area that’s either seasonally or permanently covered by shallow water.	2	4	1	3	2	3	4	3	5	5	1	33
Green walls	A with vegetation covered wall.	1	1	3	2	4	4	2	0	5	0	0	22
Parks	Parks and trees provide green space and recreational area's in the city.	3	4	5	3	3	5	4	5	5	0	1	38
Floodable waterfront parks	Waterfront parks are (recreation) area's alongside waterbodies that are able too inudated during storm events with minimal damage to park infrastructure.	5	2	3	3	3	2	3	4	4	0	0	29
Street trees / green streetscape	Green area's in streets covered by trees and / or bushes.	3	2	5	4	2	5	3	2	4	0	1	31
Natural bank stabilisation	Replacing concrete banks of streams with natural materials and vegetation.	3	4	2	2	2	3	4	4	3	5	0	32
Green deculverting/ Daylighting	Opening up burried watercourses.	3	3	1	1	1	2	4	3	5	2	2	27
Afforestation / Urban forest	Planting of new forest in the urban area.	3	4	5	5	3	5	4	4	5	0	2	40
Filter strips	Gently sloping strips of grass able to convey runoff as overland sheet flow.	1	2	0	1	1	1	1	0	1	1	0	9
Not selected measures													
Permeable pavements	Pavements made of permeable material water can seep through.	4	4	0	0	0	2	1	1	2	1	0	15
Soakaways	Burried subsurface chambers which create underground storage and infiltrate runoff.	3	1	0	1	0	0	0	0	0	1	0	6
Infiltration basin	Basin designed for stormwater infiltration.	4	1	1	1	1	1	2	4	2	1	0	18
Rain gardens	Gardens used to create storage for runoff and increase infiltration.	4	3	2	1	2	2	3	1	4	3	1	26
Infiltration trenches	Trench with gravel to create storage and infiltrate runoff.	2	3	2	0	0	2	1	0	2	2	0	14
Filter drains / trenches	Trench with drain lined with geotextile and gravel to create storage and convey runoff.	2	2	0	0	0	0	0	0	1	1	0	6

Table 31: General performance matrix of EDS and cost criteria for all NBS.

Selected measures	Short discription of solution	Ecosystem dis-services: Regulating dis-services		Supporting dis-services	Cultural dis-services	Provisioning dis-service	Cost criteria: Capital cost			Total EDS points measure	Total cost points measure	Total points measure (ES-EDS-cost)
		Animals as disease vectors	Pollen allergies	Habitat competition with humans	Aesthetical issues	Infrastructure damage	Land costs	Construction costs (m2)	Operation and maintenance cost (m2/year)			
Retention ponds	Pond designed with extra storage capacity to collect and hold stormwater runoff.	2	0	2	1	1	4	1	1	6	6	13
Rainwater harvesting	Collection and storage of rain from roofs in barrels or tanks.	1	0	0	0	0	0	1	1	1	2	7
Detention basins	Dry surface storage basin that can inudate during storm events.	2	2	2	1	0	4	2	1	7	7	8
Natural open water channels and rills	Shallow open surface water channels with hard edges to convey stormwater.	2	2	2	0	1	1	2	1	8	4	-4
Swales (all kinds)	Shallow, linear channels vegetated with grass or shrubs to convey, absorb and slow down stormwater.	1	2	1	1	1	3	1	1	6	5	11
Extensive green roofs	Green roof with a thin substrate layer covered with herbaceous vegetation and mosses.	0	2	1	1	0	0	3	5	4	8	9
Intensive green roofs	Green roof with a deep substrate layer allowing to grow gardens on rooftops.	1	1	1	1	1	0	5	5	5	10	18
Wetlands	Area that's either seasonally or permanently covered by shallow water.	2	2	2	1	0	5	3	3	8	10	15
Green walls	A with vegetation covered wall.	1	2	1	1	1	0	4	1	6	5	11
Parks	Parks and trees provide green space and recreational area's in the city.	1	3	2	2	1	5	5	1	9	11	18
Floodable waterfront parks	Waterfront parks are (recreation) area's alongside waterbodies that are able to inudated during storm events with minimal damage to park infrastructure.	1	3	2	2	1	5	5	1	8	11	10
Street trees / green streetscape	Green area's in streets covered by trees and / or bushes.	2	3	2	2	1	0	3	5	10	8	13
Natural bank stabilisation	Replacing concrete banks of streams with natural materials and vegetation.	2	2	2	1	0	2	3	5	7	10	15
Green deculverting/ Daylighting	Opening up burried watercourses.	2	2	2	1	1	2	5	2	7	9	10
Afforestation / Urban forest	Planting of new forest in the urban area.	3	3	3	3	1	5	1	1	12	7	21
Filter strips	Gently sloping strips of grass able to convey runoff as overland sheet flow.	0	1	1	0	1	3	1	1	3	5	1
Not selected measures												
Permeable pavements	Pavements made of permeable material water can seep through.	0	0	0	0	0	0	2	1	0	3	12
Soakaways	Burried subsurface chambers which create underground storage and infiltrate runoff.	0	0	0	0	0	1	3	1	0	5	1
Infiltration basin	Basin designed for stormwater infiltration.	2	2	2	1	0	4	2	1	7	7	4
Rain gardens	Gardens used to create runoff storage and increase infiltration.	1	3	2	0	1	1	5	1	7	7	12
Infiltration trenches	Trench with gravel to create storage and infiltrate runoff.	0	0	0	0	0	1	2	2	0	5	9
Filter drains / trenches	Trench with drain lined with geotextile and gravel to create storage and convey runoff.	0	0	0	0	0	1	2	1	0	4	2

Appendix B. Questionnaire development and execution

B.1. Questionnaire development

B.1.1 Choosing the weighting method

For the weighting of criteria, different Ratio Assignment Techniques can be used. Ratio Assignment Techniques are questioning methods used to assign a set of weights to the different criteria used in MCA that correspond to the user's subjective chosen preferences (Ezell et al., 2021). These questioning techniques should result in an assigned set of points or scores per criterion. From these points and scores, weights can be calculated by normalizing the score of each criterion relative to the total score of all criteria (Ezell et al., 2021).

The four most conventional and practically applicable Ratio Assignment Techniques are the Direct Assignment Technique (DAT), Simple Multi Attribute Rating Techniques (SMART), Swing Weighting Technique (SWING) and Simple Pairwise Comparison (Ezell et al., 2021). All methods have their own pros and cons.

DAT is the most straightforward weighting technique among the commonly used Ratio Assignment Techniques (Ezell et al., 2021). This method does not require any software and is easily reproducible, giving it high practical usability compared to other methods. The number of questions needed to obtain weights scales linearly with the number of attributes. Thus, the effort and time required to obtain weights is low compared to other methods, which is also beneficial for the framework. The drawback of this method is that it assumes independence among criteria, potentially resulting in equal scores and weights for different criteria. However, due to its simplicity, DAT was chosen as the best method to obtain weight input from the public (citizens).

Nonetheless, the potential use of other weighting methods was explored. Simple pairwise comparison was not chosen due to the large number of criteria used in this framework, which would require participants to make 66 pairwise comparisons ((N*N−1)/2) for the 12 ES criteria alone. This was considered too time-consuming and would impose a significant cognitive burden on the participants, making it unsuitable for use in this tool.

Both SWING and SMART were selected as unsuitable for use with general citizens due to their relatively more complicated weighting processes. This was thought to increase the likelihood of misunderstandings and non-compliance with instructions, thus preventing citizens from conducting the weighting process unassisted. Aubert et al. (2020) developed an online questionnaire to obtain criteria weights for new wastewater infrastructure in Paris using the SWING method. However, only 12% of participating citizens were able to follow the process, as they were unable to understand and comply with the basic instructions (Aubert et al., 2020). This indicates that unassisted SWING weight elicitation is challenging and not easily understandable for laypersons (Aubert et al., 2020).

B.1.2. Selected scale

The questionnaire was developed using DAT. To alleviate cognitive burden for citizens, a well-defined Likert scale ranging from 0 to 10 was used (see Figure 21). A score of 0 indicates no importance at all for the criterion, while a score of 10 represents an extremely important criterion. During the first test and feedback round of the questionnaire, there was criticism that the 11-point Likert scale would still impose a cognitive burden on citizens. Test subjects were considered to lack the knowledge necessary to make well-informed decisions between small variations on the scale for the topic of the questionnaire. For example, distinguishing between the meaning of a score of 8 and 9 on the scale.

To address this criticism, two alternative and simpler ratio scales were developed: a 5-point and a 7-point Likert scale using descriptive texts instead of numerical values (see Figure 21). During the second feedback round, 10 questionnaires were distributed to employees of RHDHV, each containing all three different scales. Participants were asked to indicate which scale they preferred. The feedback received indicated that the 7-point Likert scale with verbal descriptions was the most suitable. The 11-point scale was considered to impose too much cognitive burden on regular citizens, which confirmed the initial criticism. Participants found both the 5-point and 7-point scales suitable, but they preferred the 7-point scale because it allowed for differentiation between "very important" and "extremely important." Participants appreciated this additional nuanced response option. As a result, the 7-point Likert scale with descriptive texts was chosen to obtain importance weights.

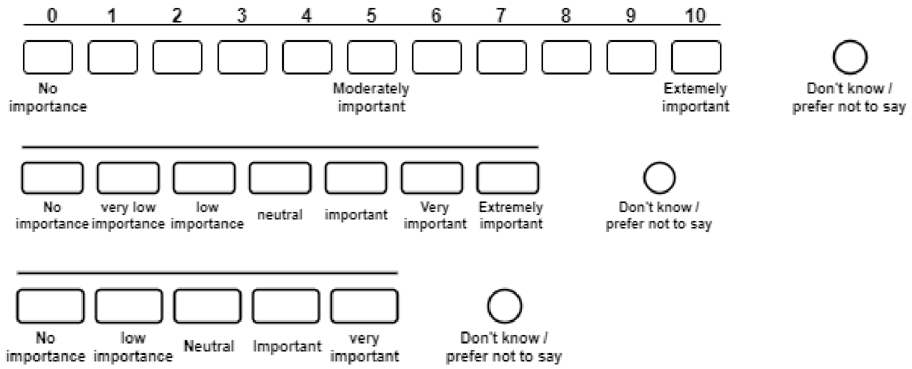

Figure 21: The 3 different Likert scales tested during questionnaire development. Top: Initial 11-point Likert scale directly showing the underlying weight scores. Middle: 7-point Likert scale with verbal descriptions. Bottom: 5-point Likert scale with verbal descriptions.

B.1.3. Questionnaire structure and properties

Both an online version and an offline paper version of the questionnaire were developed. It was thought that producing both versions would increase the response rate of participants by allowing the participates choose their preferred option. Producing a paper version of the questionnaire was also thought to make the survey more accessible for older people. For the online version of the questionnaire the survey platform Qualtrics was used. Qualtrics was chosen because of the available premium license that could be accessed by students of the TU Delft. The structure and properties of both the online and paper versions of the questionnaire are identical, except for the interface and the opening page due to the use of whole different mediums. It was chosen to make the paper questionnaire in A3 format allowing for more information per page and increased letter size letter size for people with bad eyesight.

The questionnaire starts with an opening statement briefly explaining the purpose of the research, defining the subject in simple terms, and providing instructions how to answer the questions correctly. On the paper version also a QR-code is shown to allow participants to access the online version if participants want too. On the opening page also five example pictures of NBS with short descriptions are stated to better understand and visualize the context and spark the interest of the participant. In the bottom right corner of the opening page contact information of the researchers is provided.

In the questionnaire the ecosystem services are referred to as ‘’benefits due to nature’’. The questions are all stated in the same form, namely: How important is it for you… followed up by a sentence of a positive change of a certain ecosystem service in the area. Below the question a 7-point Likert scale is provided to indicate the importance level. Also, a box allowing to tick don’t know / prefer not to say is provided. On the left of the question a picture related to the corresponding ecosystem service is provided and a short description of the positive effect is given. Allowing for a better understanding of the question. The last question asks if the participant if they think any ''benefit'' is missing, giving room to participant to allow for their own input. At the end a question is asked to rank their top three most important aspects they need improvement for the city. Functioning as both a consistency check and allowing the participant to better differentiate their most important aspects in case multiple questions are answered with the same importance level. This also allowed the citizens to elaborate their motivation why they selected a certain criterion discussed in the questionnaire as most important. This gives insight on the reason behind the chosen importance and offers insight in the thinking process of citizens regarding ES and EDS delivery in Tam Ky. The citizen interview notes can be found in Appendix D.

For Aesthetical issues the two statements ''ugly and unsafe area'' and ''view blockage'' were asked. For Infrastructure damage the two statements ''tree root damage'' and ''falling tree accidents'' were used. This was done to better grasp the concepts of those criteria.

For the ecosystem disservices the questions are asked in statement form: I'm concerned that the introduction of new water and nature inside the city will cause: Followed up by the ecosystem disservice. The 7-point Likert scale indicates levels of concern instead of importance levels. It was thought that formulating the questions in terms of concerns would trigger a stronger emotional response with participants and was more fitting to the subject. For the EDS infrastructure damage and aesthetical issues two statements per EDS were asked in terms of proxies since it was thought that only asking one direct question regarding the EDS would not generate the right response from the citizens and capture the whole subject. The weight scores from these EDS were obtained by taking the mean of both statements.

At the end of the questionnaire, five standard demographic questions were asked, inquiring about age, gender, occupation, and education. These questions were placed at the end of the survey to avoid boring participants right from the start or potentially scaring them away if they found such questions inappropriate.

At last, the questionnaire was translated to Vietnamese. This was done by word translator. The translated texts were sent to colleague Quan Nguyen Giang who corrected and improved the translated texts. Both the English and Vietnamese versions of the questionnaire are provided in appendix C. The online version can be accessed by scanning the QR code.

B.1.4. Demographics and sample size

To understand how demographic parameters or spatial location are related to the valuation of different ES and EDS, various bivariate analyses were conducted. Therefore, questions regarding age, gender, education, and type of job were asked and the interview spots were logged. This to identify patterns in responses based on differences in demographics or area. This information will help to understand how different groups of citizens value ES or EDS differently. This in return will help future users of the tool understand how much responses, which demographic distributions, and on which spatial scale the citizens questionnaire needs to be conducted to get a representative sample of perceived ES and EDS importance for the study site.

To acquire a dataset of perceptions that is representative of the population and has statistical significance, a minimum number of participants need to be recruited, ensuring they reflect the general demographics of the area. Interview locations, age distributions, and gender were monitored while employing the questionnaire to achieve this representation.

In terms of the needed sample size, it is recommended to recruit at least 50 participants to obtain statistically significant output. With this number of participants, it is possible to demonstrate statistical significance for a mean difference of 0.5 points on the Likert scale between two valued criteria, with a two-tailed 95% confidence level (p = 0.05) and a standard deviation of 1.25. It is unlikely that the standard deviation will be higher than 1.75. Therefore, having 100 questionnaire respondents for the citizens' survey should ensure obtaining statistically significant output in any case. Detailed information on how this estimate was derived is provided in the following paragraphs.

B. 1.4.1. Sample size estimates

At-test analysis is done to estimate the sample size needed to acquire statistically significant output for the questionnaire.

A first estimation of the number of respondents needed to detect significant differences between averaged means of two different groups can be tested with a two-sample t-test. In this research the groups are the questioned ES and EDS that are rated on importance in the questionnaire. It must be noted that there are more than two benefit groups in the questionnaire. Therefore, after the questionnaire is conducted also post HOC ANOVA tests needs to be done to test significant differences between the means of multiple groups.

The sample size needed to acquire statistical significance between the means of different benefits is dependent on the confidence interval, the standard deviation, that data distribution and the mean difference between both groups. To create an estimation of the required amount of questionnaire responses needed for statistical significance, different values of standard deviations and mean differences are tested.

The two groups used for this test are two benefits provided by NBS with corresponding importance weight means as obtained from the questionnaire output. For the estimation a two tailed 95% confidence interval is used (α=0.05) and the standard deviations are assumed to be equal for both groups. It can be expected that benefits that are rated with high importance are negatively skewed, whereas not important benefits have a positive skew distribution. Benefits that are valued with medium importance are expected to have a higher change to be normally distributed. For the t-test different standard deviations and mean differences are tested. All other parameters are kept constant.

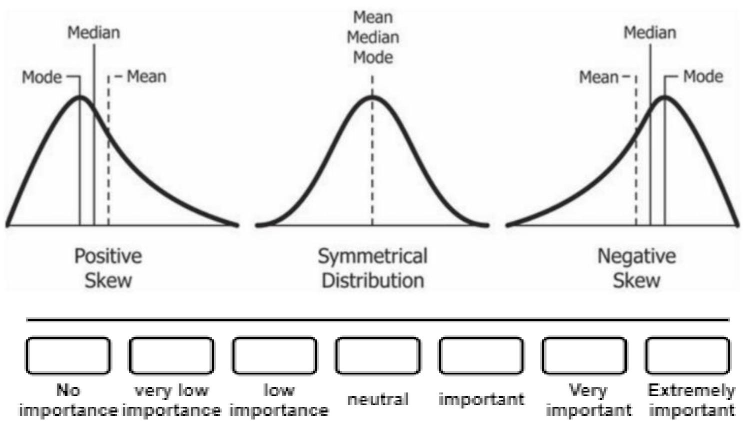

Figure 22:_High valued criteria have a higher probability to have a skewed distribution, while neutral valued criteria have a higher probability to have a symmetrical distribution (Hozo et al., 2005).

Estimating standard deviation

A general rule of thumb for estimating the standard deviation for a normal distribution is $\sigma \approx$ range / 4 (Hozo et al., 2005). Whereas for a not normal distribution the standard deviation can be estimated with $\sigma \approx$ range / 6 (Hozo et al., 2005).

The importance weights from the questionnaire are obtained from a 0-6 Likert scale. The maximum range possible is thus 6 (scale 0-6). This means the estimated standard deviation is 1.25 for a normal distribution and 1 for a skewed distribution. Since a conservative estimate on the needed sample size is made no standard deviation lower than 1.25 is considered.

Testing different standard deviations

T-test outcomes for samples with standard deviations between 1.25 and 1.75 and corresponding sample sizes to acquire statistical significance are calculated in Excel and stated below. All values above the red dotted line are statistically significant. The means difference ($\bar{X}_1$-$\bar{X}_2$) is set on a 0.5-point difference between means of two groups on the Likert scale.

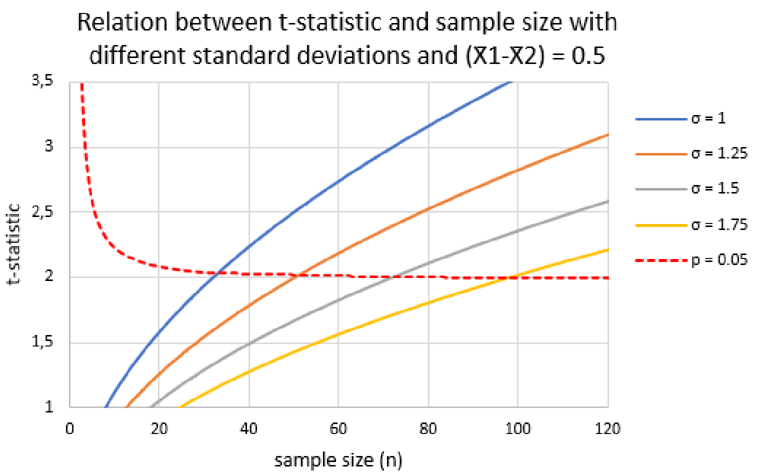

Figure 23: Relation between t-statistic and sample size with different standard deviations and a mean difference between two criteria of 0,5 point.

Testing different mean differences ($\bar{X}_1$-$\bar{X}_2$)

T-test outcomes for samples with a constant standard deviation of 1.75 (σ = 1.75) and varying mean differences between two groups are calculated. The mean difference values between 0.25 and 1 are used with an interval of 0.25.

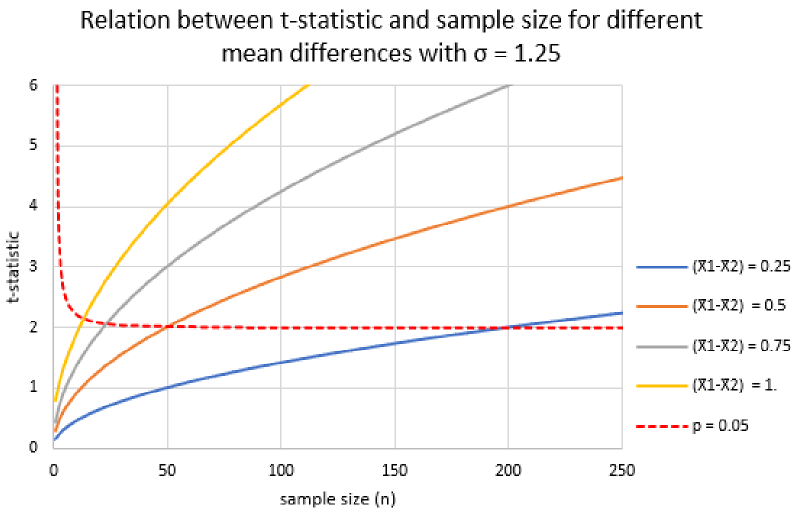

Figure 24: Relation between t-statistic and sample size with σ = 1.25 and varying mean differences between 0,25 and 1 point between the means of two criteria.

As shown in the figures above the minimum required sample is dependent on the standard deviation and the mean differences between two groups. For this research the goal is set to acquire statistical significance with a two tailed 95% confidence level (p = 0.05), a standard deviation of 1.25, and a mean difference of 0.5 point. To achieve this goal a minimum sample size of 50 is needed. A standard deviation higher than 1.75 is not estimated very likely. To reach the goal to test a 0.5 point mean difference between two groups with a confidence level of 95% it's not deemed needed to collect more than 100 questionnaire respondents for this research.

B.2. Executing the questionnaire

The method of acquiring respondents was asking citizens in the streets of the city of Tam Ky to fill in the questionnaire. Because English is not widely spoken in Tam Ky, Quan Nguyen Giang from RHDHV joined the field campaign as translator. To assure a representative sample population, it was monitored that the interview locations were distributed equally throughout the city. During the campaign it was also monitored if the population sample was representable in terms of age distributions and gender.

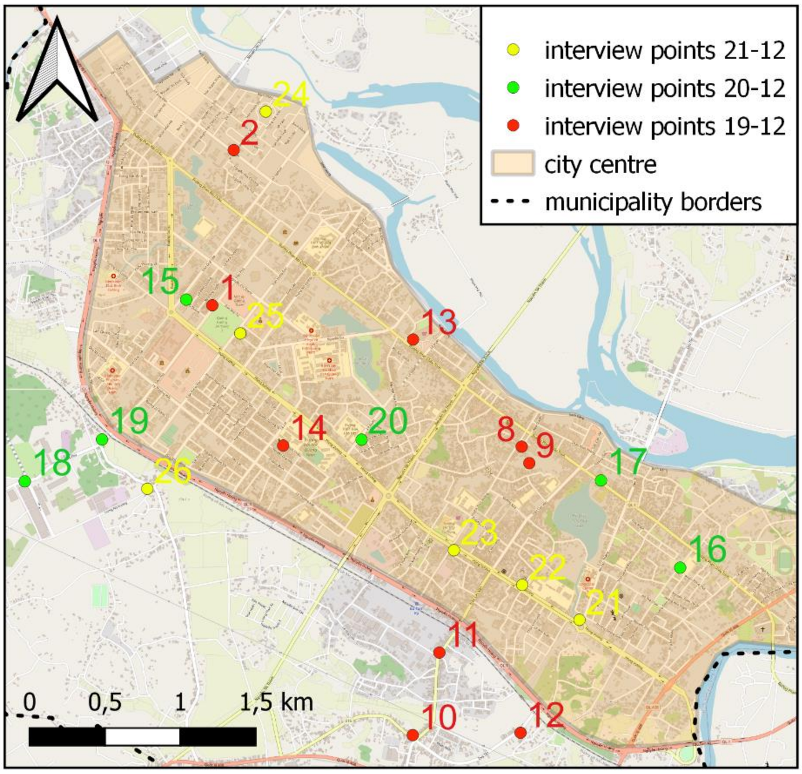

Figure 25: Spatial distribution of interview locations in Tam Ky.

People were generally very interested in the questionnaire and willing to fill in the form when approached. Overall, it seemed that the questionnaire was clear enough and well understood. People took the questionnaire seriously, read the questions carefully, and answered thoughtfully. To minimize disturbance to residents while they were working or engaged in other daily activities, only citizens who were engaged in recreational activities or appeared to have time to spare were approached to fill in the 10-minute questionnaire. The following situations were found to have the highest success rate and willingness among citizens to participate:

- People chatting and recreating in coffee shops
- Business owners / employees waiting for new customers in their shops / stands / restaurants
- People sitting on the streets near their homes
- People recreating in parks and conducting activities like socializing, doing sports or fishing.

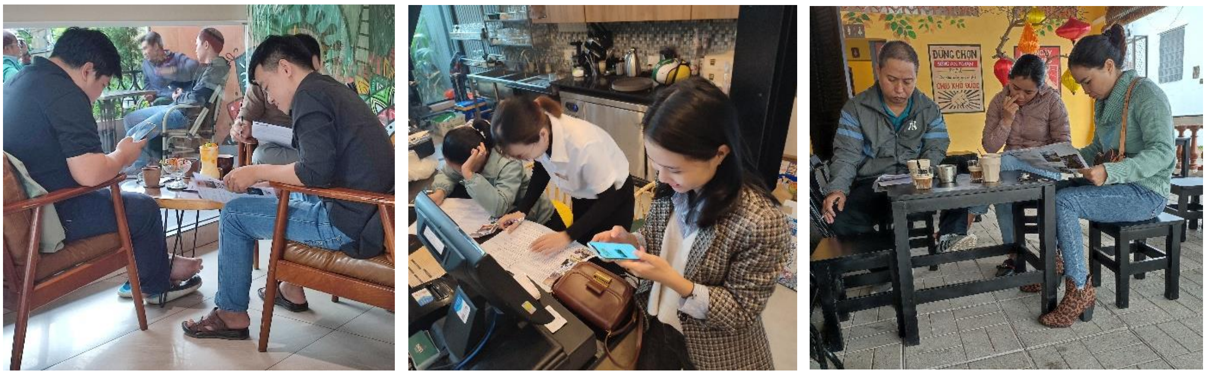

Figure 26: Picture left and right: Coffee shop costumers filling in the questionnaire before going to work. Picture middle: Restaurant owner with two employees filling in the questionnaire while taking a break.

However, most individuals older than 50 years had trouble filling in the questionnaire correctly. Older people found questions hard to understand, were rather slow or insufficient with reading and seemed not to be familiar with questionnaires or ticking boxes. The reason for this is not confirmed but it was thought to have something to do with the education in Vietnam in the past.

To address this issue, a more guided approach was taken for the older generation. The questionnaire was conducted like a structured interview. This extra guidance and explanation in Vietnamese by the translator Quan Nguyen Giang made sure all questions were well understood and answered. It also allowed for a more comprehensive view why people find certain aspects important. If people found a topic extremely important or had comments, it was written down why they find a topic extremely important. The only drawback of this approach was that it required more time due to the individualized guidance provided.

Figure 27: Translator Quan Nguyen Giang chatting with older people explaining the questionnaire questions. Picture top left and bottom left: shop owners sitting at their properties. Picture right: Old man fishing in a retention pond.

Appendix C. English and translated citizen questionnaire to obtain weighting data

Questionnaire benefits nature-based solutions

Opening statement

You are being invited to participate in a research study about the valuation of the multiple benefits of nature-based solutions. This study is being done by Max de Boer and Nguyen Giang Quan from the TU Delft and Royal HaskoningDHV.

Nature based solutions (NBS) are measures that are inspired by nature that can reduce flooding (see examples). In the future new nature-based solutions might be built to reduce the floodings in your living area. To help choose good solutions for the area, we would like to know how the multiple benefits and possible drawbacks of nature-based solutions are valued by the inhabitants of Tam Ky.

The study will take you approximately **10 minutes** to complete. The study is completely anonymous. Only personal information about age, gender and occupation will be asked. Your participation in this questionnaire is entirely voluntary, and you can withdraw at any time. You are free to omit any questions.

Scan the Qr code to access the online version of the questionnaire:

In the next questions we want you to rate how important it is for you to improve 12 different aspects for your own city that NBS can improve.

Select "no importance" when you think the aspect is not relevant, or if there is no need to improve the current situation.

For example: You are already satisfied by the current amount and quality of recreational spaces in your city and thus see no need for extra recreation spaces or improvements. You may select: no importance or very low importance to improve.

Select "very important" if you think there is a large need to improve the current situation. Select "extremely important" only if you think there is an extreme need to improve the current situation. This can for example be the case when something extremely negatively affects your health and wellbeing.

For example: The quality and number of recreational areas in your city is not sufficient, it does not fulfil your needs and is also not attractive for tourist to visit. You may select: very important or extremely important to improve.

Some examples

Retention Pond

Ponds created to store water during rainfall events. Also providing room for animals to live and area for people to recreate.

Bioswale

Shallow, landscaped depressions with plants designed to capture, treat, and infiltrate rainwater as it moves downstream.

Green roofs

A roof of a building that is partially or completely covered with plants, increasing the beauty of the building, cooling the building, and storing rainwater.

Street trees

Street trees provides shade and cooling off the area. Street trees also make the area more beautiful, intercept rainfall and improve the local air quality.

Urban wetland

Newly created wetland areas designed for additional storage capacity, which can filter out water pollution. Also providing recreational opportunities and biodiversity in the area

Contact details:

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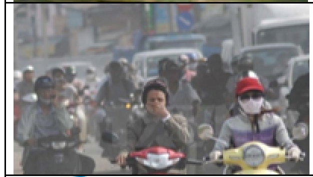
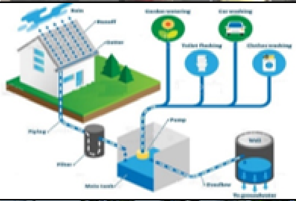
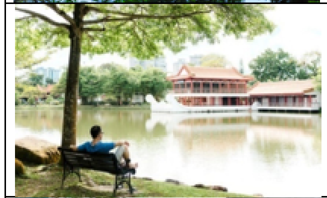
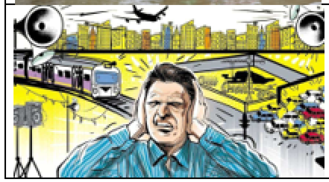
nguyen.giang.quan@rhdhv.com +84 0645081286

information		Questions
	**Water pollution** High levels of heavy metals, chemicals, (plastic) waste, excrements and nutrients pollute surface waters. Highly polluted waters can be harmful for human health, smells bad, looks ugly and is harmful for nature and wildlife. Nature-based solutions can filter out pollutions, which can lead to less polluted waters in the area.	**1. How important is it for you to decrease water pollution of both the surface water bodies inside the city and the Tam Ky River?** No importance / very low importance / low importance / neutral / important / Very important / Extremely important / Don't know / prefer not to say
	**Air pollution** Exhaust gases from traffic or industrial activities create air pollution, which lead to problems for human health, increasing respiratory and cardiovascular diseases. Plants can capture air pollutants such as fine dust particles (PM 2.5), improving the air quality in the area.	**2. How important is it for you to decrease air pollution inside the city of Tam Ky?** No importance / very low importance / low importance / neutral / important / Very important / Extremely important / Don't know / prefer not to say
	**Rainwater reuse** Rainwater that falls on roofs can be captured in storage tanks. This rainwater can later be used for new purposes such as watering the garden, flushing the toilet, or showering. This will reduce drinking water demand and costs for citizens. It also helps reducing flood risk since more rainwater is kept on the property parcels, thus reducing the amount of water that flows into the streets and sewer system.	**3. How important is it for you to reduce household water demand by using alternative water sources such as rainwater harvesting?** No importance / very low importance / low importance / neutral / important / Very important / Extremely important / Don't know / prefer not to say
	**Biodiversity and ecology** Nature based solutions can provide new nature in the area and thus new places for wildlife and various plant species to live. This can lead to a higher diversity of animal and plant species in the area, improving local biodiversity and ecology.	**4. How important is it for you to improve the biodiversity and ecology inside the city of Tam Ky?** No importance / very low importance / low importance / neutral / important / Very important / Extremely important / Don't know / prefer not to say
	**Recreational opportunities** Increasing recreation opportunities refers to the need to create additional or better recreational areas in the city. Green spaces, parks, water bodies and sport facilities all allow people to spend free time outdoors to do fun activities, improving physical and mental health and increasing the number of tourists in the area.	**5. How important is it for you to increase and improve the recreational opportunities inside the city of Tam Ky?** No importance / very low importance / low importance / neutral / important / Very important / Extremely important / Don't know / prefer not to say
	**Flood risk reduction** Flooding of the urban area can result in a loss of human life, creates damage to properties and hampers social-economic growth. Nature based solution can store water and decrease runoff, reducing the risk of flooding in the area.	**6. How important is it for you to decrease the floodings inside the city of Tam Ky?** No importance / very low importance / low importance / neutral / important / Very important / Extremely important / Don't know / prefer not to say
	**Noise reduction** Due to traffic and other human activities cities can be very noisy. This can increase stress and decrease sleep quality of inhabitants, negatively effecting human health. Plants can reflect, absorb, and refract sound waves, reducing local noise from traffic and other human activities in the area.	**7. How important is it for you to decrease the amount of noise from traffic and other human activities inside the city of Tam Ky?** No importance / very low importance / low importance / neutral / important / Very important / Extremely important / Don't know / prefer not to say

Aesthetics

Aesthetics means how beautiful a place is perceived by a person. Water bodies, green spaces and green buildings are often perceived to improve the aesthetics in an area. They create a sense of space and perspective around the buildings. Improving the aesthetics in an area can help improve mental health, increase property prices and the amount of tourist is the area.

8. **How important is it for you to improve the aesthetics inside the city of Tam Ky?**

No importance	very low importance	low importance	neutral	important	Very important	Extremely important	Don't know / prefer not to say

Urban temperature regulation

Buildings and asphalt absorb the suns heat, causing the temperatures inside cities to rise. Because of this effect cities become hotter than the surounding area. Plants can decrease local temperatures by reflecting heat, evaporating water and by providing shade, leading to cooler area's and lower temperatures in buidlings. Due to lower temperatures also the energy demand and thus costs of airconditioning in buildings can decrease.

9. **How important is it for you to increase shaded area's and decrease temperatures inside the city of Tam Ky?**

No importance	very low importance	low importance	neutral	important	Very important	Extremely important	Don't know / prefer not to say

Carbon uptake

Due to the increase of greenhouse gas emission caused by human activity the climate changes. Urban plants can capture CO_2 of the atmosphere by storing it in their leaves and branches. This reduces the annual CO_2 output of a city, thus reducing the carbon footprint of the city which helps mitigating climate change.

10. **How important is it for you increase the amount of carbon dioxide (CO_2) that can be captured out of the atmosphere due to the implementation of new plants inside the city of Tam Ky?**

No importance	very low importance	low importance	neutral	important	Very important	Extremely important	Don't know / prefer not to say

Urban food production

Green roofs, private gardens, community gardens, green spaces, and farm fields inside and surrounding the city allow for food production in the urban area. Local urban food production can improve the food security in an area, reduces costs and increases freshness of goods due to short supply chains.

11. **How important is it for you to increase local food production inside the city of Tam Ky?**

No importance	very low importance	low importance	neutral	important	Very important	Extremely important	Don't know / prefer not to say

Do you think an important direct benefit is missing?
If yes, write down below what benefit you think is missing and mark in the answer bar how important this is for you to improve:

………

12. **missing benefit**

No importance	very low importance	low importance	neutral	important	Very important	Extremely important	Don't know / prefer not to say

Please rank your <u>top 3 most important</u> aspects to improve for your city from the list above:

1. **Most important aspect:**
2. **:**
3. **:**

Negative effects of nature

Due to the implementation of nature based solutions new green spaces and waterbodies in the city will be created. This introduction of new nature in the urban area can provide all kinds of benefits for people living in the city as stated in the previous questions. However, nature can also cause processes that result in actual negative impacts for human wellbeing.

In the following questions, we would like to ask how conserned you are certain negative effects might arrise due the implementation of new nature and water-bodies in the city.

Demographic questions

1. Do you live in Tam Ky City?

A. Yes
B. No
C. Prefer not to say

2. What is your gender?

A. Male
B. Female
C. Prefer not to say

3. What is your age?

A. Under 18 years old
B. 18 – 25 years old
C. 26- 35 years old
D. 36 – 45 years old
E. 46 – 55 years old
F. 56 – 65 years old
G. Above 65 years old
H. Prefer not to say

4. What is the highest degree or level of education you have completed?

A. Primary school
B. Middle school
C. High school
D. Bachelor's degree
E. Master's degree
F. Ph.D.
G. Prefer not to say

5. What best describes your job?

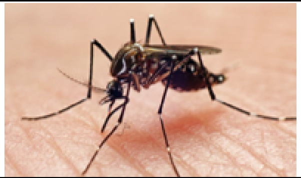
A. Researcher
B. Student
C. Business owner
D. Farmer
E. Employee private sector
F. Employee (local) government
G. Prefer not to say
H. Other, namely:

……………………………………

Statement: I'm concerned that the introduction of new water and nature inside the city will cause:

1. An increase of mosquito's, increasing the chance of mosquito-borne deseases such as dengue

No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say



2. Damage to pavement and streets due to tree roots

No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say

3. Increased number of harmfull animals such as rats, spiders, snakes and insects

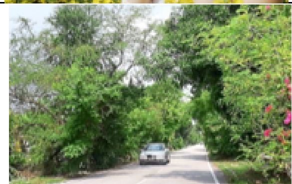
No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say

4. Allegies caused by pollen

No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say

5. A blockage of views due to trees and plants

No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say

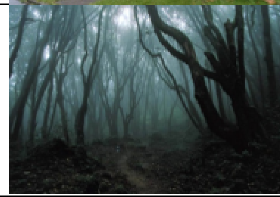


6. Accidents due to falling trees during storms

No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say

7. Percieved ugly and unsave area's due to bad maintainance of the nature in the area

No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say



8. Additional concern you have that is not on the list:

…………………………………………………………………………………………

No concern at all	very low concern	low concern	Neutral	Concerned	Very concerned	Extremly concerned	Don't know / prefer not to say

Bảng câu hỏi – Lợi ích của các giải pháp dựa trên thiên nhiên

Giới thiệu chung

Đây là một nghiên cứu đánh giá về các lợi ích của các giải pháp dựa trên thiên nhiên, được thực hiện bởi Max de Boer từ trường Đại học TU Delft (Hà Lan) và Nguyễn Giang Quân từ Công ty Tư vấn quy hoạch nguồn nước Hà Lan - Royal HaskoningDHV.

Các giải pháp dựa trên thiên nhiên (Nature-based solution - NBS) là các giải pháp khai thác sử dụng nguồn tài nguyên tự nhiên nhằm ứng phó với các vấn đề môi trường như lũ lụt, xói mòn, v.v. Trong tương lai, sẽ có nhiều các giải pháp dựa trên thiên nhiên tiềm năng để giải quyết các vấn đề về ngập lụt tại khu vực Tam Kỳ. Để lựa chọn các giải pháp tốt nhất cho khu vực, chúng tôi muốn tìm hiểu các quan điểm của người dân Tam Kỳ về tầm quan trọng cũng như các ưu/nhược điểm của từng giải pháp này.

Bảng câu hỏi này sẽ mất từ **5-10 phút** để hoàn thành. Đây là một cuộc khảo sát ẩn danh, chỉ có một vài câu hỏi về thông tin cá nhân cơ bản như tuổi tác, giới tính và nghề nghiệp. Việc tham gia vào bảng câu hỏi này là hoàn toàn tự nguyện và người tham gia có thể bỏ qua bất kỳ câu hỏi nào, cũng như dừng cuộc khảo sát này bất kỳ lúc nào.

Vui lòng quét mã QR để truy cập phiên bản trực tuyến

Trong những câu hỏi dưới đây, chúng tôi muốn bạn đánh giá tầm quan trọng trong việc cải thiện vấn đề môi trường cho 12 khía cạnh khác nhau. Đây là các vấn đề mà các giải pháp dựa trên thiên nhiên có thể hỗ trợ giải quyết và giảm thiểu.

Chọn "Không quan trọng" khi bạn nghĩ rằng vấn đề này hiện tại không nghiêm trọng, không liên quan hoặc nếu không cần phải cải thiện vấn đề này.

Chọn "Rất quan trọng " nếu bạn nghĩ rằng vấn đề này cần được giải quyết/nhu cầu giải quyết cao. Chỉ chọn "Cực kỳ quan trọng" nếu bạn nghĩ rằng vấn đề này hiện tại rất nhức nhối, cần được giải quyết ngay lập tức/mức độ khẩn cấp rất lớn . Ví dụ, khi vấn đề này hiện tại ảnh hưởng nghiêm trọng đến sức khỏe, chất lượng sống của bạn.

Một số ví dụ

Ao/hồ trữ nước

Các ao hồ tự nhiên được thiết kế để trữ nước khi xảy ra mưa, giảm thiểu ngập lụt, đồng thời tạo cảnh quan và phục vụ các hoạt động của người dân

Mái nhà xanh (green-roof)

Thảm thực vật, cây cỏ được trồng (một phần hoặc toàn phần) trên mái nhà, nhằm hấp thụ một phần lưu lượng mưa tránh gây ngập úng, điều hòa không khí cũng như tạo cảnh quan.

Vùng đất ngập nước đô thị

Xây dựng các khu vực ngập nước mới để tăng lưu tích trữ nước khi xảy ra mưa, giúp lọc và điều hòa ô nhiễm nguồn nước, tạo cảnh quan, cung cấp khu vực cho người dân khu vực sinh hoạt, giải trí

Mương lọc sinh học (Bioswale)

Mương lọc sinh học là một kiểu cảnh quan thường được thiết kế nhằm thu gom, vận chuyển, xử lý các chất gây ô nhiễm, tiêu thoát nước mưa giảm ngập úng

Cây xanh đường phố

Cây xanh trên đường phố cung cấp bóng râm, điều hòa nhiệt độ, hấp thụ một phần lưu lượng mưa giảm thiểu ngập úng, và cung cấp cảnh quan đô thị

Chi tiết liên hệ:

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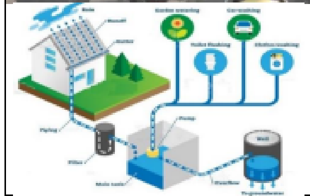
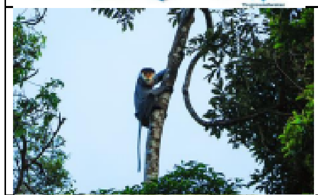
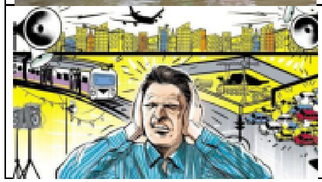
nguyen.giang.quan@rhdhv.com +84 936290995

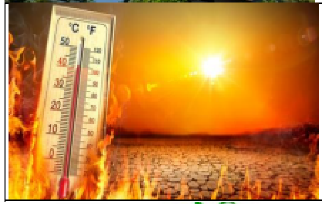
Thông tin		Câu hỏi
	**Ô nhiễm nguồn nước** Hàm lượng cao kim loại nặng, hóa chất, nhựa, chất thải và các hợp chất khác gây ô nhiễm nước mặt. Nguồn nước bị ô nhiễm mạnh gây các tác động nguy hại đến sức khỏe con người, ảnh hưởng tiêu cực đến môi trường sống và cảnh quan. Các giải pháp dựa trên thiên nhiên có thể hỗ trợ lọc/loại bỏ các hợp chất gây ô nhiễm, từ đó giảm thiểu ô nhiễm nguồn nước tại khu vực	**1. Tầm quan trọng của việc giảm ô nhiễm nguồn nước ở các vùng nước mặt bên trong thành phố và sông Tam Kỳ?** Không quan trọng Hầu như không quan trọng Ít quan trọng Mức độ quan tâm trung bình Quan trọng Rất quan trọng Cực kỳ quan trọng Không rõ / không muốn tiết lộ
	**Ô nhiễm không khí** Khí thải từ giao thông hoặc các hoạt động công nghiệp gây ra ô nhiễm không khí, làm gia tăng các bệnh về đường hô hấp và tim mạch, ảnh hưởng đến sức khỏe con người. Giải pháp dựa trên thiên nhiên bao gồm trồng cây xanh, thảm thực vật có thể xử lý các hạt bụi mịn (PM 2.5), cải thiện chất lượng không khí trong khu vực.	**2. Tầm quan trọng của việc giảm ô nhiễm không khí bên trong thành phố Tam Kỳ?** Không quan trọng Hầu như không quan trọng Ít quan trọng Mức độ quan tâm trung bình Quan trọng Rất quan trọng Cực kỳ quan trọng Không rõ / không muốn tiết lộ
	**Tái sử dụng nước mưa** Nước mưa trên mái nhà có thể được thu gom trong các bể chứa. Lượng nước mưa này sau đó được sử dụng cho nhiều mục đích như tưới cây, vườn, tắm, xả bồn cầu, v.v, giúp giảm thiểu chi phí và nhu cầu sử dụng nước sinh hoạt cho người dân. Ngoài ra, giúp giảm thiểu rủi ro ngập lụt do nước mưa được trữ trực tiếp vào các bể chứa, giảm thiểu lưu lượng mưa chảy vào đường phố và hệ thống thoát nước	**3. Tầm quan trọng của việc giải quyết nhu cầu sử dụng nước sinh hoạt thông qua các giải pháp sử dụng nước (như thu gom và tái sử dụng nước mưa)?** Không quan trọng Hầu như không quan trọng Ít quan trọng Mức độ quan tâm trung bình Quan trọng Rất quan trọng Cực kỳ quan trọng Không rõ / không muốn tiết lộ
	**Đa dạng sinh học và sinh thái** Các giải pháp dựa trên thiên nhiên có thể cung cấp các khu vực thiên nhiên mới trong khu vực, nơi sinh sống của các loài động vật và thảm thực vật. Điều này giúp gia tăng đa dạng sinh học và sinh thái của khu vực.	**4. Tầm quan trọng của việc cải thiện đa dạng sinh học và sinh thái bên trong thành phố Tam Kỳ?** Không quan trọng Hầu như không quan trọng Ít quan trọng Mức độ quan tâm trung bình Quan trọng Rất quan trọng Cực kỳ quan trọng Không rõ / không muốn tiết lộ
	**Nhu cầu giải trí** Nhu cầu giải trí đề cập đến nhu cầu tạo ra các khu vực giải trí tốt hơn cho người dân trong khu vực, bao gồm các không gian xanh, công viên, ao hồ, sân thể thao giúp người dân có không gian hoạt động thể chất, cải thiện sức khỏe, nâng cao tinh thần chất lượng sống, tạo ra các cơ hội về du lịch trong khu vực.	**5. Tầm quan trọng của việc tăng cường và cải thiện nhu cầu giải trí trong thành phố Tam Kỳ?** Không quan trọng Hầu như không quan trọng Ít quan trọng Mức độ quan tâm trung bình Quan trọng Rất quan trọng Cực kỳ quan trọng Không rõ / không muốn tiết lộ
	**Giảm thiểu rủi ro ngập lụt** Ngập lụt đô thị gây ra các tác hại nghiêm trọng đến tính mạng con người, tài sản, kìm hãm sự phát triển kinh tế-xã hội. Các giải pháp dựa trên thiên nhiên giúp trữ nước, giảm lưu lượng gây ngập, từ đó giảm thiểu rủi ro ngập lụt trong khu vực.	**6. Tầm quan trọng của việc giảm thiểu ngập lụt bên trong thành phố Tam Kỳ?** Không quan trọng Hầu như không quan trọng Ít quan trọng Mức độ quan tâm trung bình Quan trọng Rất quan trọng Cực kỳ quan trọng Không rõ / không muốn tiết lộ
	**Ô nhiễm tiếng ồn** Lưu lượng giao thông lớn cùng hoạt động của con người gây ra nhiều tiếng ồn trong khu vực. Điều này có thể làm gia tăng căng thẳng gây ảnh hưởng chất lượng sống, sức khỏe của con người. Cây cối, thảm thực vật có thể phản xạ, hấp thụ và khúc xạ sóng âm, giảm thiểu tiếng ồn từ xe cộ và các hoạt động của con người.	**7. Tầm quan trọng của việc giảm thiểu tiếng ồn từ giao thông và các hoạt động khác của con người bên trong thành phố Tam Kỳ?** Không quan trọng Hầu như không quan trọng Ít quan trọng Mức độ quan tâm trung bình Quan trọng Rất quan trọng Cực kỳ quan trọng Không rõ / không muốn tiết lộ

Cảnh quan

Cảnh quan đề cập đến giá trị vẻ đẹp của khu vực. Các vùng nước mở như sông hồ, không gian xanh, các công trình xanh thường sẽ làm gia tăng cảnh quan trong khu vực. Điều này giúp cải thiện sức khỏe, chất lượng sống của người dân, phát triển du lịch, v.v.

8. Tầm quan trọng của việc cải thiện cảnh quan bên trong thành phố Tam Kỳ?

Không quan trọng	Hầu như không quan trọng	Ít quan trọng	Mức độ quan tâm trung bình	Quan trọng	Rất quan trọng	Cực kỳ quan trọng	Không rõ / không muốn tiết lộ



Nhiệt độ đô thị

Tòa nhà, nhựa đường hấp thụ nhiệt, làm gia tăng nhiệt độ trong đô thị. Hiệu ứng nhà kính này khiến nhiệt độ tăng cao ảnh hưởng đến chất lượng sống người dân. Các giải pháp thảm thực vật, cây cối giúp giảm nhiệt độ đô thị thông qua phản xạ nhiệt, bốc hơi nước, cung cấp bóng râm, điều hòa không khí nhiệt độ, giảm tải nhu cầu về năng lượng, chi phí sử dụng điện (điều hòa) ở các tòa nhà.

9. Tầm quan trọng của việc tăng diện tích bóng râm và giảm nhiệt độ bên trong thành phố Tam Kỳ?

Không quan trọng	Hầu như không quan trọng	Ít quan trọng	Mức độ quan tâm trung bình	Quan trọng	Rất quan trọng	Cực kỳ quan trọng	Không rõ / không muốn tiết lộ

Hấp thụ carbon

Do sự gia tăng phát thải khí nhà kính gây ra bởi hoạt động của con người khiến khí hậu thay đổi. Thảm thực vật có thể hấp thụ khí CO_2 trong khí quyển thông qua cành và lá cây. Điều này làm giảm lưu lượng khí CO_2 hàng năm, giảm lượng phát thải carbon và giảm biến đổi khí hậu.

10. Tầm quan trọng của việc giảm lượng carbon dioxide (CO_2) trong khí quyển thông qua thảm thực vật trong thành phố Tam Kỳ?

Không quan trọng	Hầu như không quan trọng	Ít quan trọng	Mức độ quan tâm trung bình	Quan trọng	Rất quan trọng	Cực kỳ quan trọng	Không rõ / không muốn tiết lộ

Sản xuất thực phẩm đô thị

Mái nhà xanh, vườn tư nhân, vườn cộng đồng, không gian xanh và cánh đồng nông trại trong và xung quanh thành phố cho phép gia tăng sản xuất lương thực trong khu đô thị. Sản xuất lương thực địa phương giúp cải thiện an ninh lương thực trong khu vực, giảm chi phí và gia tăng chất lượng sản phẩm, giải quyết vấn đề thiếu hụt nguồn cung.

11. Tầm quan trọng của việc gia tăng sản lượng lương thực địa phương bên trong thành phố Tam Kỳ?

Không quan trọng	Hầu như không quan trọng	Ít quan trọng	Mức độ quan tâm trung bình	Quan trọng	Rất quan trọng	Cực kỳ quan trọng	Không rõ / không muốn tiết lộ

Có các lợi ích trực tiếp nào còn thiếu hay không?
Nếu có, bạn có thể viết thêm dưới đây, đồng thời gán mức độ quan trọng trong thang đánh giá ở bên phải:

……

12. Đánh giá bổ sung

Không quan trọng	Hầu như không quan trọng	Ít quan trọng	Mức độ quan tâm trung bình	Quan trọng	Rất quan trọng	Cực kỳ quan trọng	Không rõ / không muốn tiết lộ

Vui lòng xếp hạng 3 khía cạnh <u>quan trọng nhất</u> để cải thiện thành phố, dựa theo kết quả đánh giá bên trên

1.

2.

3.

Tác động tiêu cực của các giải pháp

Việc thực hiện các giải pháp dựa trên thiên nhiên sẽ tạo ra thêm các không gian xanh và các vùng nước mới trong thành phố. Sự thành tạo của các không gian mới này đem lại các lợi ích cụ thể cho người dân sinh sống trong khu vực, như đã đề cập. Tuy nhiên, cũng có thể gây ra một số các tác động tiêu cực đến cuộc sống con người.

Dưới đây là một số các câu hỏi liên quan đến các tác động tiềm ẩn mà các giải pháp dựa trên thiên nhiên có thể gây ra.

Tôi lo ngại các giải pháp dựa trên thiên nhiên trong thành phố sẽ gây ra:

1. Số lượng muỗi gia tăng, làm tăng khả năng mắc các dịch bệnh như sốt xuất huyết

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

2. Gây hư hỏng, phá hủy vỉa hè do rễ cây gây ra

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

3. Số lượng các loài động vật có hại gia tăng như chuột, nhện, rắn, côn trùng, v.v

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

4. Dị ứng do phấn hoa

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

5. Gây cản trở tầm nhìn do cây cối mọc nhiều

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

6. Tai nạn khi xảy ra bão lớn do đổ cây

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

7. Các khu vực tự nhiên (cây cối, thảm thực vật) không được duy tu thường xuyên làm ảnh hưởng đến cảnh quan, thiếu an toàn trong khu vực

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

8. Các vấn đề khác không có trong danh sách trên. Vui lòng điền dưới đây

....

Hoàn toàn không quan tâm	Hầu như không quan tâm	Ít quan tâm	Mức độ quan tâm trung bình	Quan tâm	Rất quan tâm	Cực kỳ quan tâm	Không rõ / không muốn tiết lộ

Thông tin cá nhân

1. Bạn có sống ở thành phố Tam Kỳ không?

A. Có
B. Không
C. Không muốn tiết lộ

2. Giới tính của bạn là gì?

A. Nam
B. Nữ
C. Không muốn tiết lộ

3. Bạn ở độ tuổi bao nhiêu?

A. Dưới 18 tuổi
B. 18 - 25 tuổi
C. 26- 35 tuổi
D. 36 – 45 tuổi
E. 46 - 55 tuổi
F. 56 – 65 tuổi
G. Trên 65 tuổi
H. Không muốn tiết lộ

4. Bằng cấp hoặc trình độ học vấn cao nhất của bạn là gì?

A. Tiểu học
B. Trung học cơ sở
C. Trung học phổ thông
D. Cử nhân đại học
E. Thạc sĩ
F. Tiến sĩ
G. Không muốn tiết lộ

5. Công việc/nghề nghiệp của bạn là gì?

A. Nhà nghiên cứu
B. Sinh viên
C. Chủ doanh nghiệp
D. Nông dân
E. Người lao động trong doanh nghiệp tư nhân
F. Nhân viên nhà nước (địa phương)
G. Không muốn tiết lộ
H. Khác, cụ thể là:

....

Cảm ơn bạn rất nhiều vì đã tham gia! 😊

Appendix D. Demographics and statistical analysis citizens Questionnaire

D. 1. Demographics

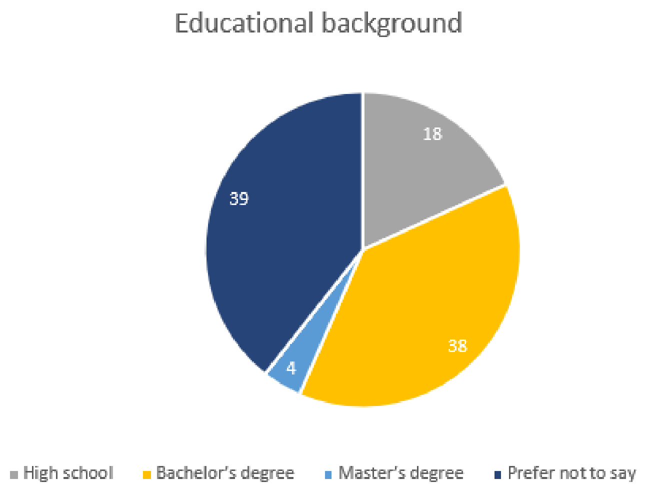


Figure 28: Pie chart of distribution educational background of participants citizens questionnaire.

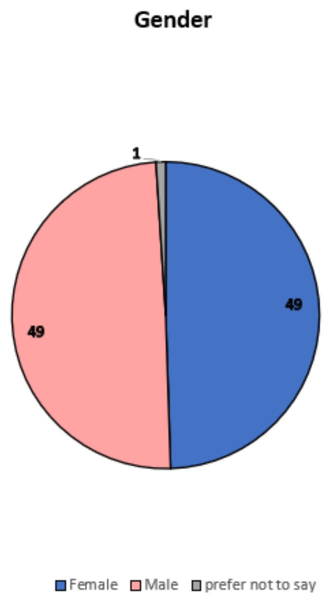


Figure 29: Pie chart of gender distribution of participants citizens questionnaire.

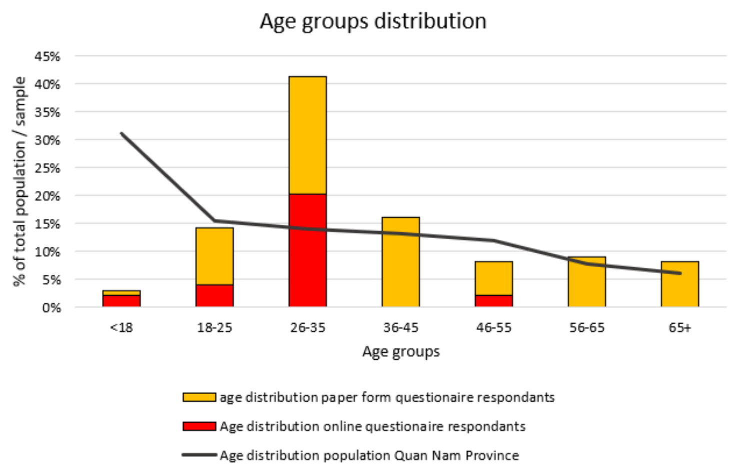


Figure 30: Age group distribution of sample compared to actual age group distribution of Quan Nam Province.

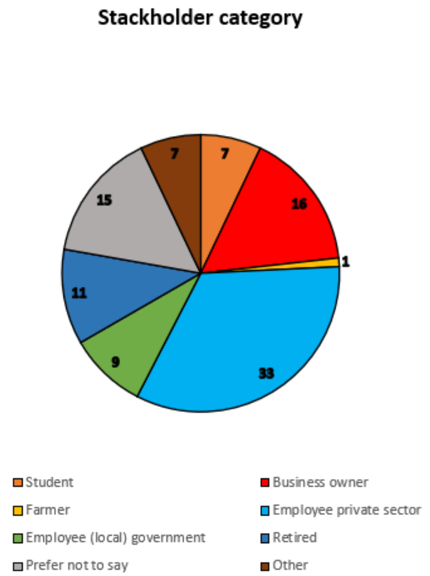


Figure 31: Pie chart of distribution stakeholder background of participants citizens questionnaire.

D. 2. Post Hoc ANOVA statistical analysis

Post HOC ANOVA statistical significance pairwise comparison matrix with Šidàk-Bonferonni correction of α [PT] = 0.000932

	Water purification	Air purification	Water capture and reuse	Habitat for biodiversity	Recreation	Flood risk reduction	Noise attenuation	Aestetics	Urban heat island mitigation	Carbon sequestration
Air purification	0,3853									
Water capture and reuse	4E-08	3E-06								
Habitat for biodiversity	0,028	0,2227	9E-05							
Recreation	0,146	0,6108	8E-06	0,4517						
flood risk reduction	2E-14	4E-15	1E-23	2E-21	6E-19					
Noise attenuation	0,0002	0,0047	0,0472	0,0601	0,0124	6E-20				
Aestetics	0,0291	0,2342	7E-05	0,9619	0,4743	6E-22	0,0527			
Urban heat island	0,2058	0,7266	6E-06	0,3719	0,3719	2E-17	0,0095	0,3907		
Carbon sequestration	5E-05	0,0002	0,0482	0,033	0,0052	4E-23	0,9145	0,028	0,0039	
Urban food production	1E-09	3E-07	0,8714	2E-05	1E-06	1E-29	0,0431	1E-05	8E-07	0,0426

Significant difference between two criteria with α [PF] = 0.05
No significant difference between two criteria with α [PF] = 0.05

Average mean differences matrix between percieved criteria (X1-X2)

	Water purification	Air purification	Water capture and reuse	Habitat for biodiversity	Recreation	Flood risk reduction	Noise attenuation	Aesthetics	heat island mitigation	n sequestration
Air purification	0,1717									
Water capture and reuse	1,3756	1,2039								
Habitat for biodiversity	0,4141	0,2424	0,9615							
Recreation	0,2726	0,1009	1,103	0,1415						
flood risk reduction	1,2828	1,4545	2,6584	1,697	1,5555					
Noise attenuation	0,8384	0,6667	0,5372	0,4242	0,5658	2,1212				
Aestetics	0,4053	0,2336	0,9703	0,0089	0,1327	1,6881	0,4331			
island mitigation	0,2424	0,0707	1,1332	0,1717	0,0302	1,5253	0,596	0,1629		
Carbon sequestration	0,8645	0,6927	0,5112	0,4503	0,5918	2,1473	0,0261	0,4592	0,622	
Urban food production	1,3338	1,1621	0,0418	0,9197	1,0612	2,6167	0,4955	0,9286	1,0914	0,4694

Difference between criteria higher than 0,69
Difference between criteria lower than 0,69

Post HOC ANOVA statistical significance pairwise comparison matrix no family wise error rate correcti

	Water purification	Air purification	Water capture and reuse	Habitat for biodiversity	Recreation	Flood risk reduction	Noise attenuation	Aesteticss	Urban heat island mitigation	Carbon sequestration
Air purification	0,3853									
Water capture and reuse	4E-08	3E-06								
Habitat for biodiversity	0,028	0,2227	9E-05							
Recreation	0,146	0,6108	8E-06	0,4517						
flood risk reduction	2E-14	4E-15	1E-23	2E-21	6E-19					
Noise attenuation	0,0002	0,0047	0,0472	0,0601	0,0124	6E-20				
Aestetics	0,0291	0,2342	7E-05	0,9619	0,4743	6E-22	0,0527			
Urban heat island	0,2058	0,7266	6E-06	0,3719	0,3719	2E-17	0,0095	0,3907		
Carbon sequestration	5E-05	0,0018	0,0482	0,033	0,0052	4E-23	0,9145	0,028	0,0039	
Urban food production	1E-09	3E-07	0,8714	2E-05	1E-06	1E-29	0,0431	1E-05	8E-07	0,0426

Significant difference between two criteria with α [PF] = 0.05
No significant difference between two criteria with α [PF] = 0.05

Average mean differences matrix between percieved criteria (X1-X2)

	Water purification	Air purification	Water capture and reuse	Habitat for biodiversity	Recreation	Flood risk reduction	Noise attenuation	Aesthetics	heat island mitigation	n sequestration
Air purification	0,1717									
Water capture and reuse	1,3756	1,2039								
Habitat for biodiversity	0,4141	0,2424	0,9615							
Recreation	0,2726	0,1009	1,103	0,1415						
flood risk reduction	1,2828	1,4545	2,6584	1,697	1,5555					
Noise attenuation	0,8384	0,6667	0,5372	0,4242	0,5658	2,1212				
Aestetics	0,4053	0,2336	0,9703	0,0089	0,1327	1,6881	0,4331			
Urban heat island mitigation	0,2424	0,0707	1,1332	0,1717	0,0302	1,5253	0,596	0,1629		
Carbon sequestration	0,8645	0,6927	0,5112	0,4503	0,5918	2,1473	0,0261	0,4592	0,622	
Urban food production	1,3338	1,1621	0,0418	0,9197	1,0612	2,6167	0,4955	0,9286	1,0914	0,4694

Difference between criteria higher than 0,45
Difference between criteria lower than 0,45

Table 32: Post Hoc ANOVA test with and without Family wise error rate correction for all ES.

The tables show when the mean difference between criteria is significant on a 95% confidence level. The mean differences between criteria are significant if the mean values of the criteria differ more than 0,69 point on the Likert scale with Bonferroni correction and 0,45 without correction.

For the tables without family wise error rate correction, it must be noted that a large probability of type I errors (false positives) exists.

The yellow number indicates the lowest mean differences between two criteria that are still statistically significantly different.

Post HOC ANOVA statistical significance pairwise comparison matrix with Šidàk-Bonferonni correction of α [PT] = 0.00244

	decease vectors	root damage	Habitat competition	pollen	view blockage	accidents
Root damage	8,87E-13					
Habitat competitio	0,001148	6,23E-06				
pollen	1,57E-26	1,47E-05	7,83E-18			
view blockage	3,03E-13	0,525805	1,2E-06	0,000541		
accidents	0,072679	8,45E-09	0,133964	8,97E-22	1,95E-09	
unsave and ugly	1,36E-07	0,018466	0,022314	2,98E-11	**0,004358**	0,000232

Significant difference between two criteria with α [PF] = 0.05
No significant difference between two criteria with α [PF] = 0.05

Average mean differences matrix between percieved criteria (X1-X2)

	Mosquitos	root damage	Habitat competiti	pollen	Habitat competiti	accidents
root damage	1,545455					
Habitat competiti	0,636364	0,909091				
pollen	2,42298	0,877525	1,786616			
view blockage	1,683396	0,137942	1,047033	0,739583		
accidents	0,352402	1,193053	0,283962	2,070578	1,330995	
unsave and ugly	1,072894	0,472561	0,43653	1,350086	**0,610503**	0,72049
	4,464646	2,919192	3,828283	2,041667	2,78125	4,11224

Difference between criteria higher than 0,6105
Difference between criteria lower than 0,6105

Post HOC ANOVA Statistical significance pairwise comparison matrix no Šidàk-Bonferonni correction

	decease vectors	root damage	Habitat competition	pollen	view blockage	accidents
Root damage	8,87E-13					
Habitat competiti	0,001148	6,23E-06				
pollen	1,57E-26	1,47E-05	7,83E-18			
view blockage	3,03E-13	0,525805	1,2E-06	0,000541		
accidents	0,072679	8,45E-09	0,133964	8,97E-22	1,95E-09	
unsave and ugly	1,36E-07	0,018466	**0,022314**	2,98E-11	0,004358	0,000232

Significant difference between two criteria with α [PF] = 0.05
No significant difference between two criteria with α [PF] = 0.05

Average mean differences matrix between percieved criteria (X1-X2)

	Mosquitos	root dama	Habitat competiti	pollen	Habitat competiti	accidents
root dama	1,545455					
Habitat competiti	0,636364	0,909091				
pollen	2,42298	0,877525	1,786616			
Habitat competiti	1,683396	0,137942	1,047033	0,739583		
accidents	0,352402	1,193053	0,283962	2,070578	1,330995	
unsave ar	1,072894	0,472561	**0,43653**	1,350086	0,610503	0,720492

Difference between criteria higher than 0,436
Difference between criteria lower than 0,436

Table 33: Post Hoc ANOVA test with and without Family wise error rate correction for all EDS.

The tables show when the mean difference between criteria is significant on a 95% confidence level. The mean differences between criteria are significant if the mean values of the criteria differ more than 0,61 point on the Likert scale with Bonferroni correction and 0,44 without correction.

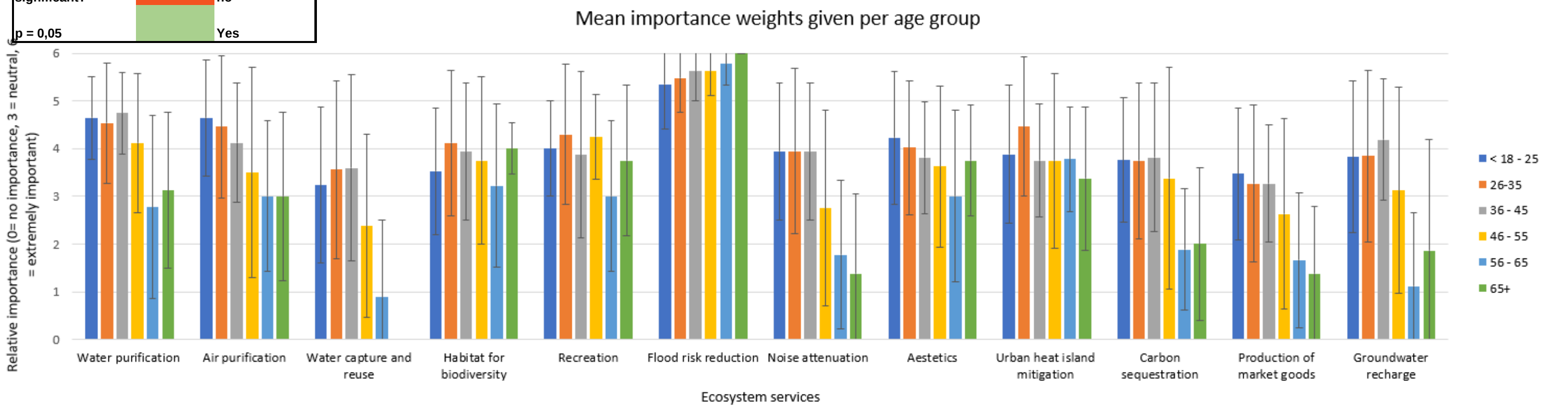
For the tables without family wise error rate correction, it must be noted that a large probability of type I errors (false positives) exists.

The yellow number indicates the lowest mean differences between two criteria that are still statistically significantly different.

D. 3. Bivariate analysis age groups and ES/EDS perceptions

Student t-test tests: Age group <18-45 against older age groups	Water purification	Air purification	Water capture and reuse	Habitat for biodiversity	Recreation	Flood risk reduction	Noise attenuation	Aestetics	Urban heat island mitigation	Carbon sequestration	Production of market goods	Animals as disease vectors	Damage to infrastructure	Habitat competition with humans	Pollen allergies	View blockage	Accidents	Ugly and unsafe area's
46-55	0,1994054	0,0583730	0,0798121	0,6930293	0,8046561	0,6467434	0,0429715	0,8740000	0,4125121	0,5422400	0,5633200	0,0029283	0,4032494	0,3154000	0,4615069	0,3332100	0,4732000	0,3783000
56-65	0,0000076	0,0014206	0,0000292	0,1271904	0,0144825	0,3063484	0,0001125	0,0199418	0,3942484	0,0001926	0,0017340	0,0000000	0,0147603	0,0000475	0,7345916	0,0030729	0,0050084	0,2313000
65+	0,0002155	0,0000891	0,0000001	0,9065884	0,4205875	0,0862620	0,0000200	0,5169900	0,1159407	0,0010288	0,0005188	0,0000089	0,0043438	0,0097488	0,7418064	0,0264210	0,0006500	0,1667139

significant?		no
p = 0,05		Yes



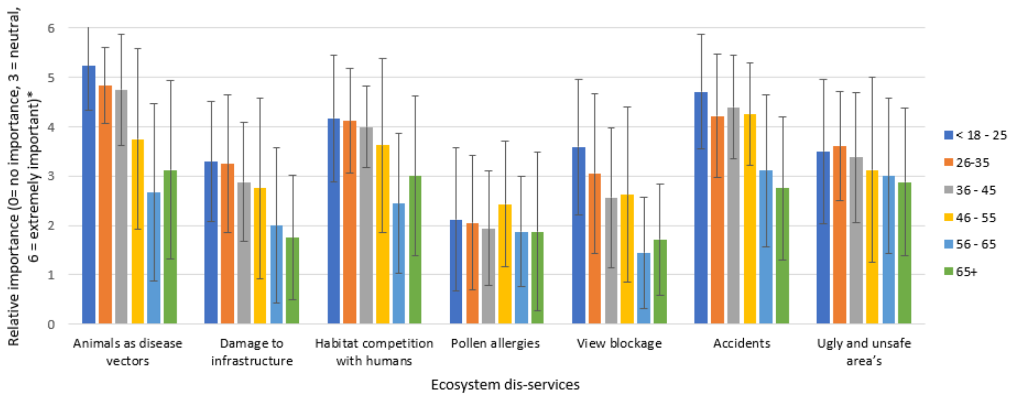
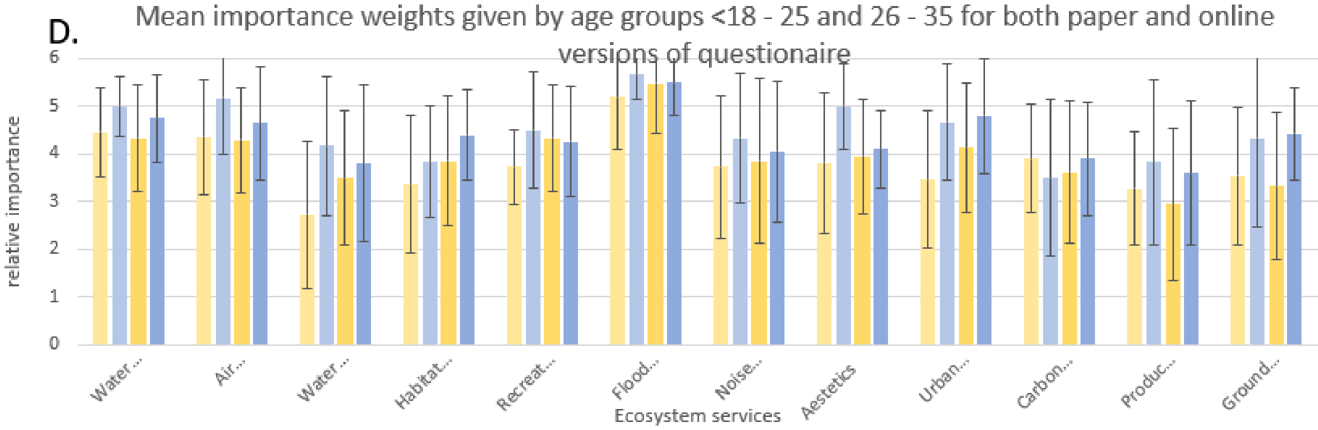


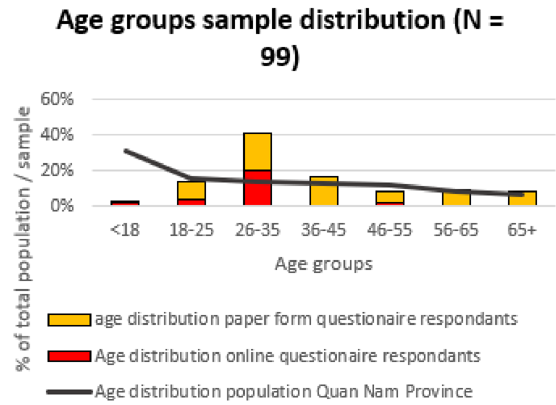
Figure 32: Bivariate analyses age groups and ES/EDS perceptions. Data indicates lower valuation ES & EDS for older population. In general, also decreasing trend visible between age and criteria valuation. Inverse visible for flood risk reduction. The older the population the higher flood reduction valued and more consensus (lower standard deviation).

D. 4. Bivariate analysis differences paper and online version

D.



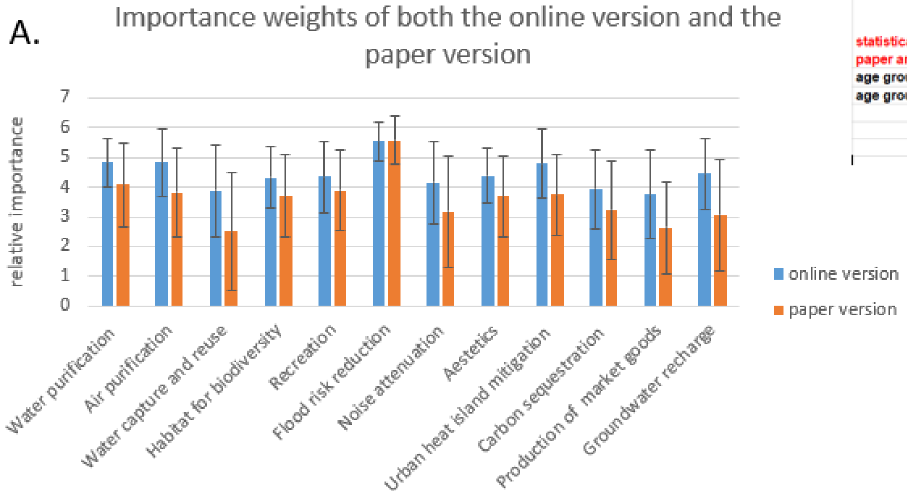
C.



statistical difference paper and online?	water polution	air polution	rainwater reuse	biodiverity and ecology	recreational oppertunities	flood risk reduction	noise reduction	Aestetics	Urban temperature regulation	carbon uptake	Urban food production
age group <18 - 25	0.124	0.205	0.0831641	0.504	0.365	0.321	0.283	0.095	0.101	0.55	0.37
age group 26 - 35	0.198	0.314	0.421	0.242	0.313	0.931	0.462	0.532	0.108	0.211	0.189

no
yes

A.



B.

	water polution	air polution	rainwater reuse	biodiverity and ecology	recreational oppertunities	flood risk reduction	noise reduction	Aestetics	Urban temperature regulation	carbon uptake	Urban food production
statistical diff paper and	0.001434246	0.0007837	0.0004955	0.0153388	0.113597024	0.786799	0.0059557	0.0059385	0.0003373	0.034211	0.0017668

p = 0.05
no
yes

- Statistical differences visible between weights given online and paper version except on recreation and flood risk. (A+B)
- Paper version more old people that filled in questionnaire, online version almost only young people age <18 till 35, thus hypotheses: effect due to age difference. (C)
- When comparing the same age groups of both versions, visible that people of same age in online version gives higher weights than paper versions. Effect not statistical significant except for GWR for age group 25-36. Effect can be coincidental. But still the higher weighting in online version can be because interface differences. (D)
- Overall effect probably part due age differences and not statistical significant differences between same age group online and paper. This effect maybe due to interface differences in the online version or coincidence. Not statistically proven that that online version yields different results for same age groups.

Appendix E. Interview notes

E. 1. Interview notes with local citizens

At the end of the questionnaire citizens could indicate their most important chosen criteria. During the citizens survey citizens were asked why they selected a certain criterion discussed in the questionnaire as most important. Only a limited number of respondents could be asked to elaborate on their responses given due to time constraint and language barriers. On the following pages the cited argumentation of interviewed citizens is presented. The number in front of the respondent indicates the location at which the response was acquired, as presented on the map of figure 26.

1. **19-12-2022 9:10 Coffee Loi, Middle aged man**

Most important: Rainwater capture and reuse

‘’I think Rainwater capture and reuse is super important because there are still a lot of poor people in the rural area’s directly surrounding the city that do not have a good water supply. They are still reliable on groundwater for water use, but the groundwater is at many places not of good quality. Sometimes the wells become contaminated or salty. The rainwater reuse measures are very beneficial for the poorer people so they can use it for showering and watering the gardens’’.

8. 19-12 10:45 Old woman near big old tree

Most important: reduce flooding, heat reduction

‘’It can become very hot here in summer. It is better to have more plants and trees in the area that can provide us with shade, like this very big old tree near my house. I would like to see more old trees like this, they make the city more beautiful, but all the trees in Tam Ky are still very young and small.’’

9. 19-12 11.00 Old man fishing at newly developed retention pond.

Most important: Flood risk reduction and water quality improvements

‘’Fishing here is not good. The water here is very polluted, so it is not healthy to eat the fish. I’m just fishing here for recreational purposes. Sometimes young people here eat the fish they catch but I think it is very unhealthy to do. So, for me an improvement of water quality is very important. Sometimes the pond smells very bad. So bad that it even ‘’decreases the air quality’’. The water quality so very bad and it even irritates my eyes.’’

‘’This pond sometimes overflows. The capacity of the pond is not enough, I think.’’

9. 19-12 11.15 Man living next to newly develop retention pond

Most important: 1. Decrease flood risk 2. improve surface water quality

‘’I live here (indicates house) next to the pond’’.

''For me the flooding is most important. The floodings here in this area were very bad until around 5 years ago when the pond was built. Before the pond the whole area here flooded every wet season. The water came up all the way up into the houses (indicates a Hight +-30 cm). Now with the pond the local capacity here is increased. The ponds still sometimes overflow but these floodings are minor and short compared to the past, the new pond works well.''

''The water quality is not only important for me but for all the people surrounding this pond. This pond is heavy polluted. It sometimes also smells very bad. It is just not nice to live next to something like this.''

''Water reuse and groundwater recharge are not important at all for this area. We receive all our water from the treatment plant anyway, so I don't see use in this.''

10. 19-12 14:30 Man near Southeast border Tam Ky.

Most important: 1. Flooding, 2. Water pollution, 3. Air quality and Heat reduction

''At this location is no flooding but 200 m down that way near the highway is. Very annoying for the people there so I put it as most important. We have a local groundwater pollution here. We do not know the cause of it. Luckily, we now have water from the treatment plant, so we do not have to use the polluted groundwater anymore.''

''The air quality is very bad here because of all the trucks that drive by and the nearby industrial shops. It also becomes very hot in this area in summer since there are no trees in this street. Therefore, I would like to have more trees here.''

11. 19-12 15:00 Old woman selling noodles on the street. SE Tam Ky

Most important: 1. Reduce flooding, 2. Increase water reuse, 3. Heat reduction

''I still use the groundwater for all water use. Because I still use the groundwater, I find groundwater recharge very important. Because an Increased in recharge also increases the volume of water, I can use from the well. I really like the shade of the trees. Also, the trees absorb rainwater, so the street dry quicker after rainfall.'' (Probably describes interception here)

12. 19-12. 15:30 Old couple at their shop. South-East Tam Ky

Most important: 1. Reduce flooding, 2. Decrease air pollution 3. Noise attenuation

''The road they build here around 10 years ago was not designed well. It blocks the natural flow of the water. So, water cannot be drained anymore. This creates a lot of flooding in the area here. The drainage pipes here below the road are too small, so this creates lots of local flooding in this area. The water flows from the street aera into our backyard. There is a need to improve & enlarge the outflow pipes in this area.''

''We choose air pollution and noise reduction since due to the workshops here across the street it is often very noisy and dusty here. This is very annoying.''

17. 20-12. 12:30 Woman and Man, owners of chicken restaurant.

Most important: Reduce flood risk

''For me the only important aspects I see is flooding. The sewer system in this area is old. During heavy flooding the streets floods. Not deep though, around 10 cm, but it occurs often. I think other issues are not relevant for me. Only more shade to reduce heat would be beneficial for me. For me the only negative aspects I'm concerned about is possible tree damages during storms. If a tree falls on your shop, we must pay for all the damages ourselves. There is no insurance for something like this. The government will provide no money from damages from their trees in the streets.''

19. 20-12 15:15 Lady near railway, South border urban core

Most important: Water quality improvement.

''People cannot use groundwater, groundwater here is contaminated since people put their waste underground (in sceptic tanks). Which leak and pollute the groundwater.''

''Trees here will be cut before storm season. Government keeps the trees well, so I'm not worried about damages or bad maintenance due to extra nature.''

23. 21-12. 11.00 Young coffee shop employee Oanh Ca Coffee

Important: 1. Flood risk reduction. 2. Aesthetics. 3. Recreation

''Besides the obvious flooding issues, I picked Aesthetics and recreation because I think Tam Ky is a bit boring. I worked in Hoi An for 2 years in a restaurant. There it was much more pretty and more fun. Tam Ky should also be more like Hoi An, more tourist from Hoi An area will also then come here. I think all roads and parks are so plain and boring. If nature-based solutions can make it less boring and more beautiful here, I think that would be great.''

23. 21-12 11.15 Man at coffeeshop Oanh Ca

''Tam Ky is a young city; it needs more city planning and improve its status. Many issues must follow the policy of city development in the long term. Regarding this aspect I do not think issues related to different aspects of nature are too important to the city right now.''

23. 21-12 11.30 Man drinking coffee (searching for job)

Most important: Noise pollution, tree damage during storms

''Picked noise pollution as most important because I get woken up often at night, people drive to hard at night or people play karaoke until late at night. Also, lot of trucks drive by my house, this is all very annoying.''

''In Tam Ky damages due to trees happen often. During hurricanes accidents due to falling branches on motorbikes happen often. The government has good policy to mitigate this, but it is still a big issue.''

25. 22-12 16:35 Man at Coffee bar Eden

Most important: 1. Water pollution, 2: Noise reduction

''I picked water pollution as most important because my house here in Tam Ky is near a meat factory. The factory dumps all their meat waste into the surface waters and pollutes it. Because of this it sometimes smells horrible at my house.''

''The same factory creates lot of noise at my house also. It is very annoying.''

28. 22-12 11.30 Interview with English teacher Yen, PTH coffee

1. Flood risk reduction and controlling mosquito's 2. Aesthetics, 3. Recreation

''After flooding I picked improvement of the city landscape and recreational opportunities as most important. Before the pandemic I worked as a tour guide in Hoi An for many years. Because of the pandemic i now work in Tam Ky as an English teacher.''

''I picked these too aspects because they relate to tourism. Right now, no tourists go to Tam Ky because there is nothing fun to do or special to see. It should be developed more, I think. The local government does not promote it or does not put any effort in it to increase tourism, while being very close to a major tourist hotspot (Danang, Hoi an). For example, Tam Ky has built a very large and very expensive war statue nearby and nobody knows about it! Because all established tourism is very nearby, I think it is a great opportunity for Tam Ky to also increase it here. More nature in the area can increase this. If we develop and promote tours here and in the countryside areas tourist can do the same kinds of tours they do in Hoi an. (Biking tours, food tours, cooking classes, learning farming practices). Make the areas more attractive and not so boring like all the green spaces here.''

''Mosquitoes are a very big problem in this area, I think. Many people here get Dengue. I needed to go to the hospital a few months ago for a few days (not dengue related). There were so many people in the hospital because of Dengue there was not even a bed for me anymore and I had to stay in the hallway!''

30. 22-12 13.00 Lyka Coffee. HR employee at HBE (health & environmental related company)

Most important: 1. Water capture and reuse 2. Urban food production

''I put water reuse as most important. Currently my company is constructing a large water reuse storage tank at the office location. It is a big company office: 1000 employees. There are building 1000 m^2 of collection area. The water collected will be used to water the office gardens and to flush all the toilets. This new water collection system will save the company a lot of annual water costs. Groundwater recharge I put also as most important for the same reasons as rainwater reuse.''

''Urban Local food production, especially on roofs, is also important because it does create 3 things: - it reduces the heat of the buildings. – It provides local produced food. – and it creates recreation.''

E.2. Interview notes governmental decision-makers on NBS implementation Tam Ky.

On Tuesday 20-12-2022 three interviews with local governmental decision in the fields of urban water and environmental management for Tam Ky were conducted. During the semi-structured interviews, the interviewees were asked about their knowledge on the local characteristics listed in table 2 for the case study area. Also, questions are asked regarding the functioning of the water and sewer system, to identify the type of flooding, causes of failure for the urban drainage system and the most problematic areas for the case study and cities ecosystem service needs to better understand the decision context. The interviewees were also asked to rank the top three most important ecosystem service needs besides flooding for the area and is asked why and where these aspects are insufficient. Also, the interviewees were asked which kind of NBS their governmental body is already familiar with, and which types of NBS they think are not applicable in the area due to physical, technical, or political barriers. This helps the user identify if there actually is a need for multifunctional NBS and if the area is suitable for implementing such solutions. At last, the interviewees were asked their opinion regarding the importance of three considered cost criteria.

Table 34: Names and expertise of interviewed governmental decision-makers. The colors indicate which citation is from which person. The questions asked are stated in black.

Name	Expertise/background
Le Kieu Thanh	Environmental engineer at the Quang Nam department of natural resources and environment (DONRE)
Nguyen Van Huong	Hydrologist at the water division of the Quang Nam department of natural resources and environment (DONRE)
Nguyen Quoc Ky	Project manager at project management unit (PMU) of transportation that manages the world bank project for flood protection for Tam Ky area

Questions regarding urban drainage system and flooding

What is the main type of flooding in the considered urban area when there is a heavy rainfall event?

''The water from the 2 catchments flowing into Tam Ky do not contribute a lot to flooding, but it does not make the situation better either. The most problems occur due to inundation of the river and due to direct rainfall impact, that cause the urban drainage system to overflow''.

''It is because of the direct rainfall impacts. Not because of flash flooding due to water from these smaller catchments.''

What is the sewer system type in the area?

''Combined sewer system, without WWTP''

What is / are the main cause(s) of failure of the urban drainage system? (Such as: blocked pipes / closed manholes / inaccessible drains / small pipes)

''In 1997 most of the urban drainage system was build. System is more than 20 years old so pipes in some areas are too small. System is too small for the fast-growing city. Culverts and manholes are designed too small to accommodate for the rainstorms. Also, the culverts block often due to litter. Therefore, we are currently upgrading the old manholes in a lot of new streets to new ones. The new ones have spikes in between them so that big litter cannot pass anymore.''

''We have 3 different drainage issues in Tam Ky. These are the 3 priorities':

The big one is the urban pluvial flooding issues. The urban drainage water system has a to low capacity to drain to the city. Pipes are designed too small. The stormwater drainage system needs to get made bigger and have more subbranches branches in the streets. The second important this is domestic wastewater. We do not have a wastewater treatment plant yet, but it is under development. To bring all the wastewater from households to the plant we need to build the domestic wastewater sewer system. This is a very big project; we did not start yet. When this is done it, both helps reduce flooding and it also really improves the water quality which is also a big issue. The low priority is the water from the industrial areas. This is also polluted and sometimes floods. The drainage systems here are separate from the urban ones, more need to improve urban system so lowers priority.''

Can you indicate (on map) where inundation occurs most often during heavy rainfall? And how often this does occur?

''Most often in the older parts of the city and on Hung Vuong Road, often during heavy rainstorm in wet season. The floodings are short but occur often. Exactly how much I do not know''

''Well basically after every heavy rainfall event. At most places the floodings last short though and are also not very deep (+-15 cm). I indicated on map the streets I see always flooded during heavy rainfall. I cross this area a lot, maybe there are more places, but I never see since I do not cross there.''

Are there already measures planned in the future to improve the urban drainage system? If yes: what are these measures?

''We are going to upgrade the drainage system in Hung Vuong Street. We are going to replace 6 km here with new drainage system. There is now lots of short but intense flooding here in these areas surrounding these streets. The whole system will be made bigger. We are not started yet but we will start soon (probably next year). We are currently replacing a lot of culverts throughout the city.''

''Also, 2 months ago, new budget to increase storage capacity has been approved. Danang university signed a contract with Worldbank recently to come up with new storage solutions for in the city''

Questions regarding local site characteristics

What is the soil type in the area? Do you have data regarding soil infiltration rates? In case no, can you indicate the soil infiltration capacity in the area on a scale from very low to high?

''Heavy clay soil in the area. This maybe also increase the problem, but I can't confirm for sure since I do not know the infiltration rates. Clay soil is everywhere in Tam Ky. There is only one area in the city that has sand soil. (Indicated on map)''.

Is there soil erosion in the area? Does this sedimentation create problems for the drainage system?

''I don't know. ''

Do you have information about the average water table heights in the area?

Are there any groundwater abstractions? Is there subsidence in the area? If so, how big is this problem?

''There is no more groundwater use in the city center. We have a good water supply from the upstream lake. Since there a no groundwater abstractions in the city center. There are also no problems with groundwater abstractions. That I know of, there is also no subsidence in the area.''

What is the average drainage slope in the area? What is the maximum drainage slope in the area?

Questions about NBS

Are you familiar of the concept of nature-based solutions?

''Yes, we are familiar with these kinds of solutions. We think these kinds of solutions are very good for Tam Ky. We recently had a workshop about them (did not indicate from who). We are very supportive for these kinds of solutions.''

How strongly does your department and executives support the idea and use of NBS for your city?

''I'm the executive and I support it a lot. We support the idea; we think it's very good and beneficial for the city. We only do not have a lot of knowledge on solutions because the concepts are very new to us. (except for retention ponds). But we would like to learn more about this topic.''

In the following sheet 24 common and possible applicable NBS for your city to reduce pluvial or flash flooding for your city are shown with small descriptions. From this list, are there any solutions you are already familiar with?

''Yes, the retention ponds, we already have a lot of these ponds in the area and are currently building more''. No other solutions yet, we hope solutions like this can be applied. It may be cheaper and better than the sewer system. We currently have not enough information about these kinds of solutions to implements them are what should be good to implement (except retention ponds). I really like the concept and these sorts of solutions, and I think it is a good idea for the city. I did not know a lot of these options yet, but now that I have seen them, I have more knowledge and I like them a lot.''

''Yes, we have lots of retention ponds. Also, we are planting lots of street trees, we hope they reduce the dust and noisy problems for us in the city.''

''Yes, Interacted with these kinds of solutions quite a lot. I helped working at the integrated masterplan in Thu Bồn river project. Currently we have a lot of retention ponds.''

Can you select 3 solutions from the list you prefer to implement?

- Urban wetland area. Large place for this. We need to have some land available for this.
- Street trees. More trees in the city for greener spaces.
- Permeable pavements. I like these kinds of pavements because I learned from the workshop, they are easy and cheap to implement. We currently do not have it yet, but it would be a nice solution, I think. We should do study about the applicability of this.

- More retention ponds
- Wetland areas surrounding city.
- Street trees increasing the density of the trees. The trees also solve the noise and the dust problem.

''Solutions most feasible to implement:

1. More street trees

This is super easy to do, cheap, and helps us with the main goals set as DONRE. We are currently already doing extra street tree planting also. Trees provide shade, help take up Co2 and help with the air pollution problem we have with the dust and traffic pollution. The one thing about the trees is that the trees must be storm resilient.

2. More retention ponds.

We already have them, so we have most engineering knowledge of all nature-based solutions. It works quite well for the area; therefore, we are currently building more and plan to build even more in the future. The retention ponds are the backbone / core of the water system in Tam Ky

3. urban wetland

Improve the aesthetics and make better landscape while also provide flood risk reduction. The wetlands must surround the city. In the city there is not enough space for it so it will be accommodated around the city.''

Can you indicate which solutions in your opinion have a low applicability in the area due to local political, technical, social, or environmental constraints?

''Green roofs and walls I think not applicable: rain intensity too high for the green goofs, the plants can die. In summer to dry, the plants will die, to long no rain. It's not appropriate for this area. Very high temperature on the walls, the leaves cannot withstand this and burn. The green walls will die in this climate. No space for urban forest no space for it here. The rate of urbanization is too high in the area to develop something like this. These solutions will never happen.

One potential measure is slow down urbanization and have mores space left for green developments. We can reforest the area near eastern part of city. And near the aqua culture area. The mangrove forest is important for the aquaculture development it protects the aquaculture from salinization. Reforest the mangrove area nearby is my recommendation. Other reforest options no space. When reforest, reforest with local species this is better for ecosystem.

Solutions based on infiltration: the rainfall is super intense in a short duration. It's not useful in this area due to the intent rainfall and a slow infiltration rate due to clay soil. Water infiltrates, but its way to slow. The rainfall characteristics are not good for infiltration-based options. Only excavated, refilled with rocks, and drained infiltration trenches might work.

Green waterfront (floodable parks): Very carefully selected vegetation that can survive the summer without water and winter under water during high flow. It's feasible. But we don't have the proper land for this in the city right now. We can only build a normal park. We need to dredge our retention ponds more regularity to remove the sedimentation in the ponds and improve capacity. This management is lacking.''

''I think all are applicable except the green roofs. The roof types are just not suitable for Tam Ky. We have only inclined roofs. Only flat roofs on some big government buildings or malls. There it can be implemented but I do not know if the construction standards set in Vietnam are sufficient to hold the extra weigh capacity you need for a green roof. I think you will find not a lot of support of these kinds of solutions here in Vietnam.''

Questions about cities ecosystem service needs

Which 3 ecosystem services besides the reduction of flooding are most important to improve for your city? Can you rank these 3 ecosystem services in terms of priority to improve in a top 3? Can you also elaborate why you chose these 3 ecosystem services as most important for the city? What are the main causes that these ecosystem services are insufficient / need to be improved?

''1. Air pollution control.

During the dry season there is a lot of air pollution in Tam Ky. Especially in the busier commercial areas and in the industrial areas. There is a lot of dust also. We are currently looking for solutions to mitigate this problem with DONRE.

2. Noise reduction. Calm and quit is good for development.

3. Carbon sequestering. It's good for helping reduce climate change. ''

''1. Improving the noisy problem in the industrial areas. We are currently developing a noise monitoring system in the area to comply with the noise standard set by MONRE. Tam Ky does not comply with the rules currently. The noise monitoring program should get insight on when and how much the area does not comply with the standards. It also works as a warning system for citizens and for the factories.

2.Decreasing air pollution. Lots of dust come from the transport which decrease air quality. The air pollution is mostly a problem during the dry season. We do this by planting new trees and caring for green areas. We do this to decrease the air pollution and for noise pollution. We planted a lot of new trees in Tam Ky last years. We now focused on planting a lot of trees in the industrial areas to reduce the noise and dust problem from the area. The trees need a lot of long-term care to become big. The caretaking is much work. The trees are prone to collapse during storm season because they still have a shallow root system. We need to support all the trees to prevent this.

3.Increasing the water quality by improving the drainage systems.''

''1. Heat reduction: It's becoming very hot in summer; trees provide the shade, so we really focus on planting more trees to keep the city cool in the hot season.

2. Water pollution: directly affect the beauty of the city. During the dry season this problem gets very bad. Bad smell, bad for health of the residents.

3. Air pollution: Now there is no air pollution at all, but We have an air pollution problem during the dry season. This is for a big part due to heavy traffic inside the city and the sand and concrete factory's just outside the city. Fine dust particles from these area's blow over the city and create pollution. We hope also the trees help a bit by decreasing this problem for us. ''

Are there already measures planned in the future to improve these ecosystem services?

''Recommendations we make for not using this kind of trucks in the area. Since they produce a lot of noise and dust. We are now making new regulation to make it mandatory to use covers on the trucks so no dust can escape from the trucks while driving. The other plan is planting more street trees in Tam Ky and increasing the density of the trees to prevent the dust to blow away over the city. Most focus for tree planting at the sources, industrial areas. And of course, tree planting and noise monitoring program as previously discussed.''

''Tree planting, mostly in the streets''

Is there a special distribution in your chosen ES? Is there a different need for different ES in certain areas in your city? If so, can you indicate this on the map?

''Air pollution and noise pollution problems in the industrial area and commercial old center. Very crowded. The streets are too small here. We need improvements in these areas.''.

'Noise and air pollution problems in and surrounding industrial areas. See map''

''No, only for the flooding. Indicated on map''

Which of these goals / aspects do you think are not relevant or important at all? And why do you think these goals are not important?

''Rainwater reuse, urban food production and groundwater. We all use it for all the drink water in the area. Because of this we don't use groundwater because of this anymore. Because of this we do not care about the groundwater anymore and rainwater reuse is thus also irrelevant, Rainwater use is not a problem also because of this. The water quality of the lake above us is one of the best of whole Vietnam. For the urban food production this I think is a very personal question. I just do not care about this, but other people might.''

''Groundwater recharge and water reuse are not useful. We don't do water abstractions and have a steady clean irrigation and drinking water supply from the reservoir lake. Urban food production is also not relevant because it's very individual and not possible with current space.''

Are there any other goals for improvement of the city in the future that we did not discuss but are very relevant? If so, can you please elaborate.

''no'',

''Yes: We are going to make a wastewater treatment plant in the area for domestic wastewater. This will improve the water quality of the river (location on map).''

' ''no''

Questions about possible ecosystem dis-services

Which possible negative effects (ecosystem disservices) do you think are important to consider when creating new nature in the area? Why is (are) this negative effect(s) likely to occur in the area? And where would these negative effects likely occur?

''Mosquito's, mosquito's bring decease and we always must be very aware of them and exterminate them when possible. Also, when developing new water areas, we most always focus on this. I think other negative effects are also important. We need to maintain the green areas and the trees to prevent damage during storms''.

''Damages due to falling trees. This is the most important aspect for Tam Ky. (Already explained why important earlier). Lot of work for government to prevent this issue. This work only becomes more and more in the future due to the increase of city trees.''

''Infrastructure damage due to trees. We manage the trees in Tam Ky in 3 different ways to make them storm resilient:

1. We are planting only species of trees that are storm resilient species.
2. We support the trees while they are still young.

3. We do yearly maintenance of all the street trees before the storm season starts. We cut off all large branches and keep old the large old trees small with small canopy so that they do not fall over during typhoon. Also, then less branches can fall off which can cause some serious damages on people with bikes.''

E.2.1. Questions about cost

Different NBS require different space requirements and costs for implementation and maintenance. Which of the 3 major sorts of cost related to the implementation of new NBS, namely: land acquisition, construction cost, and operation and maintenance cost is most important to you for the selection of a new NBS? And how would you rate the importance of these cost factors on a scale from not important to extremely important?

''I think all three are important. But the construction cost related to the solution is most important to us, since the budged is limited due to the planned sewer upgrades.''

Construction cost: extremely important

Maintenance cost: important

Land requirement: important

''I think all three are very important to consider, I would rank all 3 as very important. We do not have a lot of suitable land left for large solutions, because we already needed to convert a lot of land to retention ponds in the past. Also, maintenance work of street trees has increased over the years, we do not have the current capacity to maintain more trees or other solutions right now.''

Construction cost: very important

Maintenance cost: very important

Land requirement: very important

''Compared to the major cities we still have a lot of space left to implement solutions, but the urbanization rate in the city is fast, and suitable land for such large solutions in the city is very scarce and land prices have increased a lot over the last decade, so I would say land requirement as most important. Implementation and maintenance cost are also important, but I think increased maintenance also creates new jobs, which is good for the economy.''

Construction cost: very important

Maintenance cost: important

Land requirement: extremely important