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Water, nature and people: Addressing urban water issues through Nature-based Solutions in Cartagena, Colombia

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ABSTRACT OF THESIS submitted by:

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Cities around the world are facing new challenges because urban population growth and climate change are intensifying, creating pressure for water and other urban resources, and posing significant challenges to urban management. NBS offer an approach that focuses on enhancing natural processes to provide environmental, social, and economic benefits, at the same time. This thesis investigates the application of Nature-Based Solutions (NBS) to address urban water issues in Cartagena, Colombia, and covers strategic ecosystems such as La Ciénaga de la Virgen, the Juan Angola River, and the Bay of Cartagena. Through interviews with local stakeholders and literature analysis, the study assesses the effectiveness of NBS interventions in enhancing urban resilience and water management. The results indicate that while NBS projects in Cartagena have the potential to improve the city, their success is still hindered by limited monitoring, a lack of long-term planning, and a lack of political continuity. Additionally, projects are constrained by socio-political dynamics and conditions commonly found in developing countries. Despite these challenges, collaborative efforts between public institutions, local communities, and different sectors provide a promising foundation for improving NBS implementation in the present and the future. The study concludes that in order for NBS to achieve its full potential in Cartagena, there needs to be a more structured approach to data collection, increased stakeholder engagement, and stronger alignment with urban policies. Future research should focus on broadening stakeholder involvement and enhancing understanding of NBS impacts through comprehensive monitoring and evaluation.

Keywords “Nature-Based Solutions”, “urban water management”, “ecological restoration”, “Cartagena”, “Colombia”, “collaboration”, “urban resilience”.

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List of abbreviations

Cardique	Regional Autonomous Corporation of the Canal del Dique - (Corporación Autónoma Regional del Canal del Dique in Spanish)
EPA Cartagena	Environmental Public Establishment of Cartagena (Establecimiento Público Ambiental de Cartagena in Spanish)
ESRI	Environmental Systems Research Institute
GIS	Geographic information system
IUCN	International Union for Conservation of Nature
Minambiente	Ministerio de Ambiente y Desarrollo Sostenible
NASA	National Aeronautics and Space Administration
NBS	Nature-Based Solutions
SES	Socio-Ecological Systems
UN	United Nations

1. Introduction

The world is changing, human beings are becoming an urban species. (Gross 2016), with half of us living in cities right now and urban population growth expected to increase to 58% in the next 50 years (Gross 2016; UN Habitat 2022). This transformation to an urban lifestyle involves growing consumption and higher demand on the environment to provide goods and contributions related to water, energy, food, materials, etc. (Abunyewah et al. 2023), which combined with increasing global concerns such as climate change create significant challenges that are stretching the management capacity of cities to the limit (Carter et al. 2015).

These challenges apply to different resources, such as air with 70% of human-induced greenhouse gases emitted in cities (United Nations Human Settlements Programme 2011), but also water, a non-substitutable resource, essential for both human and ecosystem well-being (Xu and Wu 2017) That is being affected by a rise in demand and a decrease in supply and quality (United Nations Human Settlements Programme 2011). “The number of people at risk from floods is projected to rise from 1.2 billion today to around 1.6 billion in 2050 (nearly 20% of the world’s population.” (WWAP (United Nations World Water Assessment Programme)/UN-Water. 2018, 15). Many cities around the world are struggling with addressing water issues through their standard approaches (Niemczynowicz 1999; Onanuga, Eludoyin, and Ofoezie 2022), this is illustrated by well-publicized cases around the world when major cities faced the risk of running out of water (e.g., Cape Town – (Rodina 2019)) or failed to maintain acceptable water quality and adequate hydraulic infrastructure, with dire implications for human health and well-being (e.g., Mumbai – (Graham, Desai, and McFarlane 2013)).

But solving the multidimensional and interconnected issues related to the meeting of human needs while also sustainably managing urban ecosystems requires novel approaches such as Nature-Based Solutions (NBS) (Seddon et al. 2021). “NBS are increasingly recognized as a promising means to address a number of societal challenges arising from climate change and urbanization, with multiple social, environmental and economic co-benefits.” (Ershad Sarabi et al. 2019, 15). NBS represent an opportunity to make more systematic and purposeful use of both traditional and novel types of green infrastructure to address water and water-related problems in cities (Acreman et al. 2021; Andersson et al. 2022; Dorst et al. 2019), and they have the potential to provide long-term solutions to societal challenges while providing benefits to people and biodiversity at the same time (Seddon et al. 2021; Turner et al. 2022).

Even though water-related NBS are increasingly used, we are still in an early part of the learning curve (Sowińska-Świerkosz and García 2022), we still don’t know the mechanisms with which NBS transform a socio-ecological system (Woroniecki et al. 2023). For this reason is important to look at empirical evidence associated with the management and use of water-related urban NBS so that we can deploy them more widely and with more effectiveness (Midgley et al. 2021; Turner et al. 2022). This is particularly important in the major cities of the global South, which are growing at a fast rate, generally have limited capacity, and are often confronting both local limitations due to poverty and outdated infrastructure and global impacts due to climate change (Luna-Galván and Vargas-Chaves 2018; Richerzhagen et al. 2019).

Cartagena, Colombia is one example of everything we have mentioned, by 2050 it is estimated that nearly 84% of Colombians will inhabit urban areas (Erickson-Quiroz 2016) and some climate

change estimations foresee dangerous impacts on local population and residential infrastructure, an example is the estimation that a 2°C rise in temperature would increase sea level and leave 25% of the city affected by floods during high tides (Richerzhagen et al. 2019).

The key objective of this research will be identifying How is Cartagena implementing water-related NBS and what are their results.

The key research questions will be the following:

- What are some of the key water-related challenges in Cartagena?
- What are some prominent examples of water-related NBS?
- What do we know about their implementation strategies and effectiveness?
- What do these tell us about the role of NBS in addressing urban water challenges in the future?

With this research, I aim to provide insights that will be of relevance to decision-makers and a broader range of social stakeholders in Cartagena, but also interest to other cities in Colombia and in Latin America and beyond, primarily in the global South. I also aim to contribute to the growing body of empirical and theoretical academic research on NBS.

To reach this objective and answer these questions the following question guides my research How is Cartagena implementing water-related NBS and what are their results? In Chapter 2, I demonstrate that despite NBS being a concept defined and categorized by several authors, the methods to evaluate the effectiveness and the impacts they produce on socio-ecological systems are almost nonexistent because there are too many factors and contexts to consider, especially in

developing countries. However, certain approaches indicate variables that could lead to NBS effectiveness This is true specially in the NBS literature that uses concepts and theories from the Socio-Ecological system, which provides the theoretical framework for my investigation and gives my findings environmental relevance alongside the management and decision-making applications as I outline in Chapter 3. To answer this question, I performed primary data collection with interviews and surveys, secondary data search with academic and grey literature, and thematic analysis as detailed in Chapter 4. I present the results of this analysis in Chapter 5, and I discuss in Chapter 6 that the projects, plans, and programs that involve NBS in Cartagena include variables that both support and hinder the effectiveness of NBS. In Chapter 7 I conclude that NBS present in Cartagena have mixed results and need further work that is synchronized with structural changes in Cartagena and Colombia.

This research will also be of relevance for the recently started Horizon Europe-funded Naturescapes project that will look at functional linkages between NBS at the landscape level in Cartagena, as one of its 12 core case studies (https://www.naturescapes-project.com/).

2. Literature review and theoretical framework

In this chapter we will review relevant literature in the field of Nature-Based Solutions (NBS) and the requirements for their implementation. I will describe NBS, explain their relevance in the context of environmental change, their impacts on socio-ecological systems (SES), and then the aspects of variables that affect the effectiveness of NBS and the achievement of their goals. The chapter will also provide an overview of sustainability challenges in the case study, Cartagena, Colombia.

2.1 What are Nature-Based Solutions?

NBS are a recent concept that has been used in the last decade to describe actions that try to solve environmental, social, and economic problems in urban and rural contexts (Dorst et al. 2019; Sowińska-Świerkosz and García 2022). But even though the concept is new, NBS was founded in years of research about ecology and urban sustainability (Mell, Clement, and O'Sullivan 2023). The first time the concept was used was in the year 2008 by the World Bank (Sowińska-Świerkosz and García 2022) and after 2015 official definitions were released by international institutions such as the European Commission and the IUCN ((Dorst et al. 2019; Sowińska-Świerkosz and García 2022). Since then, we have experienced many publications discussed of several literature about what is an NBS, what or is not an NBS, what does it do, and many other questions about its efficiency and requirements (Dorst et al. 2019). Some authors focus on the differences between NBS and other environmental interventions, for instance, Dorst and colleagues suggest that NBS is an umbrella term for green infrastructure, ecosystem-based adaptation, ecosystem services, and eco-engineering (2019). Other authors (e.g Ershad Sarabi et al. 2019) delineate consider NBS as interventions that focus equally on both humans and the environment, without favoring one or the

other (2019), while authors such as Finch et al., and Sowińska-Świerkosz and García state that NBS must include benefits to biodiversity to be considered successful (2023; 2022).On the other hand, Woroniecki et al. explain that NBS cannot be completely efficient if they do not address societal challenges (2023).

Also, NBS is a concept often associated with grey and green infrastructure, grey infrastructure is defined as engineering structures that provide services to society (Anderson et al. 2022), green infrastructure is a "strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services" (European Commission 2019, 2) The same concept includes blue infrastructure but it refers to aquatic ecosystems. There is also another concept and it is hybrid infrastructure, it is defined as a combination of biophysical structures, characteristic processes present in ecosystems, and built human infrastructure (Andersson et al. 2022). NBS can be considered a hybrid infrastructure in some studies (Andersson et al. 2022). NBS are more focused on working with nature and they have the potential to provide more benefits than only one type of infrastructure (Turner et al. 2022; Anderson et al. 2022).

Sowińska-Świerkosz and García explain that NBS are actions that are inspired and powered by nature, tackle specific challenges, provide multiple benefits, and have a certain level of effectiveness and efficiency (2022). Being inspired and powered by nature means that the actions are modeled on biological processes and have "clearly defined goals, partners, beneficiary groups and management systems" (Sowińska-Świerkosz and García 2022, 6). Tackling challenges means that NBS have an identified problem that they are trying to solve, always looking to improve or

maintain biodiversity, which is related to the characteristic of providing multiple benefits, meaning that NBS has to provide environmental, social, and economic benefits at the same time (Sowińska-Świerkosz and García 2022).

Alongside this definition, we will include the concept and categories provided by the EU Horizon 2020 NATURVATION PROJECT that explains that NBS are "interventions that change or enhance the function of the area/structure to address existing/current societal challenges" (Almassy, Pinter, and Maia 2017, 14). The categories of NBS are:

- Building greens, such as green roofs, green walls or facades, and balcony green.
- Urban green areas connected to grey infrastructure such as alley and street trees, hedges, greens, railroad banks and tracks, house gardens, green playground/school grounds, institutional green space, green parking lots, and riverbank greens.
- Parks and (semi)natural urban green areas like large urban parks or forests, Pocket parks, neighborhood green spaces, botanical gardens, and green corridors.
- Allotments and community gardens such as allotments, community gardens, and horticulture.
- Green indoor areas such as indoor vertical greeneries and atriums.
- Blue areas like lakes, ponds, rivers, streams, canals, estuaries, delta, seacoast, wetlands, bog, fens, marsh.
- Green areas for water management such as rain gardens, swales, filter strips, and sustainable urban drainage systems.

- Derelict areas such as abandoned and derelict spaces with growth of wilderness or green features.

These categories were chosen for this research because they are practical and facilitate the identification of projects and NBS at the scale of a city, but we can find other systems of classification depending on the context of the NBS and its goals. This has been seen in the case of the CONNECTING Nature project explained by Dushkova and Haase, here they classify NBS according to the scale of implementation, with meso- and microscales like buildings, neighborhoods, and cities (2023). Another example is a classification according to the degree of intervention, Ershad Sarabi et al. illustrate 3 types of NBS: minimal or no intervention, moderate intervention, and highly intensive intervention (2019), the spectrum goes from actions of monitoring and planning to management plans, installation of infrastructure, and completely changing an ecosystem (Ershad Sarabi et al. 2019).

2.2 Why do we implement NBS?

Nature-based solutions are being implemented in cities all around the world because of their multifunctional nature and because they tackle several sustainability challenges at the same time. (Turner et al. 2022; Dorst et al. 2019; Sowińska-Świerkosz and García 2022). In cities, they are being implemented to promote sustainable urbanization because they provide benefits such as enhancing water retention, pollution reduction, biodiversity conservation, reducing heat stress, increasing carbon storage, and improving community livelihoods (Dushkova and Haase 2023; Beumer and Martens 2013).

One sector that is widely targeted by NBS is the water sector because issues around water are of high concern, due to the threats of environmental change, and because they are associated with social and environmental challenges (Palomo et al. 2021; Mell, Clement, and O'Sullivan 2023; Martin et al. 2021). NBS that are focused on the water are mostly actions for sustainable water drainage systems, water treatments, wetland management, rainwater management, and others, and most of them include goals for disaster risk management and urban resilience (Dushkova and Haase 2023).

But besides impacts on water, it has been documented that these actions have the potential to affect a socio-ecological system (SES) more broadly in the short and long term (Turner et al. 2022; Palomo et al. 2021). For instance, Dorst and colleagues explain that NBS brings societal benefits by solving immediate issues such as the one concerning urban planning (e.g. by managing climate-related risks) and provision of ecosystem services (e.g. by providing green areas that support public health) (2019). But addressing immediate issues with NBS also affects the long-term problems of an SES like a city, because using nature and its processes as a course of action to achieve a goal promotes sustainable urban development (Mell, Clement, and O'Sullivan 2023), and promoting sustainable urban development additionally promotes urban regeneration and resilience (Lafortezza and Sanesi 2019).

2.3 NBS and resilience

In the context of SES, resilience is defined as "the magnitude of disturbance that can be absorbed before a system changes to a radically different state as well as the capacity to self-organize and the capacity for adaptation to emerging circumstances" (Adger 2006, 1). Resilience to global

challenges and their manifestations such as climate change is a focus in the NBS literature because if they are focused on longevity and include long-term financing, NBS can have effects on an SES in the long term (Beumer and Martens 2013; Dushkova and Haase 2023). For instance, by addressing biodiversity loss and habitat protection NBS could promote climate change adaptation of different species (Finch et al. 2023) and by concentrating on social issues NBS can provide spaces for the co-creation of knowledge and increase social capacity building with environmental education (Dushkova and Haase 2023). Environmental education is related to NBS because these projects can improve the capacity of a community by collaborating with educational institutions and citizen science strategies (Stefanakis 2022; Restemeyer and Boogaard 2021; Calderón Cendejas et al. 2021).

Specifically, NBS have the potential to improve the resilience of urban and rural SES because they enhance the capacity of the SES to resist and adapt to disturbances related to environmental threats (heatwaves, coastal erosion, flooding, etc.) (Ershad Sarabi et al. 2019) and because they strengthen the relationship between people and their environment by teaching about the dynamics of their ecosystems, their connections, how to manage them and also, depending on the case, empowering historically marginalized communities (Turner et al. 2022; Dunlop et al. 2024). In a review of different cases of NBS that target resilience to climate change, Turner and colleagues conceptualized the different elements of an SES that influence socio-ecological resilience and how NBS affects said elements, the author called them "resilience mechanisms" (2022). These mechanisms are related to the NBS governance systems, and its processes of designing, implementing, and monitoring, and they teach researchers what types of NBS are promoting resilience because it indicates if the intervention is managing known and unknown threats (Turner

et al. 2022). They categorized the mechanisms according to the influence of the ecological, social, and governance subsystems, an example of a social mechanism is the diversity of actors, an example of an ecological mechanism is landscape heterogeneity, and for governance mechanisms local communities participation (Turner et al. 2022). The authors reported that NBS in fact influence at least one of the resilience mechanisms and that they interact with each other, for example, an NBS can promote human agency that allows people to make decisions on their own by including local knowledge and bottom-up types of governance (Turner et al. 2022).

On the other hand, we can analyze the impacts of NBS on socio-ecological resilience by focusing on the reduction of vulnerability, which is the study performed by Woroniecki and colleagues (2023). Vulnerability is defined as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger 2006, 1) NBS has the potential to target the social and environmental aspects of this susceptibility to harm by physically intervening in the space and improving socio-ecological relationships (Woroniecki et al. 2023). NBS specially addresses this because they can act as natural barriers from hazards (environmental and social), reduce sensitivity, and therefore protect the ecological attributes that the NBS is targeting (Woroniecki et al. 2023). For instance, the authors found that there were cases where NBS reduced ecological sensitivity by protecting the soil and restoring land, and social sensitivity by promoting sustainable use of natural resources, and that is common that NBS addresses ecological and social sensitivity synergistically (Woroniecki et al. 2023).

Another concept that is relevant in the literature on NBS and climate change resilience is social equity (Dushkova and Haase 2023; Turner et al. 2022). In several cases around the world, NBS is

associated with unequal distribution of social, environmental, and economic benefits of NBS (Mell, Clement, and O'Sullivan 2023; Santiago Fink 2016) but the solution can be found in the processes behind the planning, implementation, and monitoring of NBS, if NBS consider a collaborative approach where the strategies of the projects are co-created by a community then the project can guarantee "equal access to neighborhood green space, fostering social cohesion (e.g., bridging and bonding social capital) toward the cultural integration of typically excluded social groups, like the elderly, immigrants, persons with disabilities"(Dushkova and Haase 2023, 10).

2.4 But how can NBS advance transformation towards increased resilience in cities?

The question of NBS effectiveness has been addressed by several authors in the literature, especially because we don't have systematically applied methods to gather evidence on the efficacy of NBS across different scales (Ershad Sarabi et al. 2019; Palomo et al. 2021). But still, we can find proposals such as sets of indicators, barriers, enablers, drivers, and factors that could contribute to NBS effectiveness and provide measurements of the impacts of the interventions (Mori et al. 2023). Nevertheless, it is important to mention that we are still waiting for a consensus on global methods that evaluate the performance of NBS (Palomo et al. 2021).

The efforts toward gathering evidence of the effectiveness of NBS have brought us a set of variables that can be analyzed depending on their context (Martin et al. 2021). For instance, Sowińska-Świerkosz and García propose four dimensions that NBS have to address to be considered effective first, management and governance capabilities that open spaces for collaborative approaches and adaptive management, second the representation of the local context, third economic efficiency of the project and fourth the provision of services by NBS (2022).

For this research, we work with variables that influence the effectiveness of NBS according to the literature, however, it is important to mention that the categories are author-specific and the delineation between concepts and themes is not always clear. For instance, for some authors governance is directly related to financial arrangements but others do not combine them. Also, land tenure could be a variable on its own or be part of the policy framework of the context. The variables selected in this analysis and included in this chapter are governance arrangements, policy framework, contextual preconditions, participation and collaboration, monitoring, Communication and acceptance, social justice and equity, and strategic management cycle. The selected variables were intended to support the analysis of the context of Cartagena and selected specific NBS cases.

2.4.1 Governance arrangements

Governance is defined by Martin and colleagues as "all formal and informal processes and conditions through which society or groups within it, including government, businesses, civil society organizations, among others, organize to make policy decisions and realize societal aims"(2021, 3), and it is influenced by "processes, conditions, or factors that play a positive role in how government, market, and civil society actors or stakeholders organize to make policy decisions on NBS at different stages of their realization" (Martin et al. 2021, 3). Governance is a topic widely discussed in the literature, especially when it comes to natural resource management (Martin et al. 2021). A relevant topic for natural resource management is polycentric governance, defined as arrangements with several decision-making centers that work on more than one scale and level (Ostrom 1999). These arrangements of polycentric governance have been identified as aspects that improved the effectiveness of NBS (Dorst et al. 2019; Turner et al. 2022). An example

of a polycentric governance arrangement is a public-private partnership (Sekulova et al. 2021) as long as the decisions are not only being taken by private actors but also public authorities that are supposed to have democratic accountability mechanisms and guarantee justice (Martin et al. 2021).

The governance arrangements, polycentric or not, are a critical variable to the long-term effectiveness of NBS (Woroniecki et al. 2023; Mell, Clement, and O'Sullivan 2023), and the governance of NBS is multifaceted and generally depends on a large number of actors and different levels of organization (Woroniecki et al. 2023), meaning that it requires collaboration among jurisdictional scales and sectors, but the governance arrangements that we see in different SES depend completely on the context of that SES (Martin et al. 2021). However, according to the authors, the governance of NBS should not just follow the context of an SES but should promote change towards equality and tackle exclusionary practices that affect a community (Sekulova et al. 2021). Governance of NBS can also follow other classifications, such as the ones associated with bottom-up or top-down approaches, and in the literature, bottom-up approaches achieve best results in NBS (Midgley et al. 2021). Top-down approaches could also be called Hierarchical Governance (Phuong, Biesbroek, and Wals 2018).

A relevant aspect of governance that is relevant for the analysis of the variable is financial arrangements (Martin et al. 2021; Midgley et al. 2021) because governance affects directly the investments and funding schemes of NBS, the sources being either the government and private companies, civil society or hybrid (Midgley et al. 2021). Asking questions about the governance and financing of an NBS is relevant because they can promote long-term changes in a landscape (Mell, Clement, and O'Sullivan 2023), and long-term financial arrangements improve the

effectiveness of NBS (Ershad Sarabi et al. 2019). However, it is common to find cases in the literature where NBS are mostly publicly funded, which means that NBS are short-term and at some point will require the input of additional funding sources (Ershad Sarabi et al. 2019).

The analysis of the financial arrangements of NBS depends on the author, it could be an independent variable that depends on the context (Martin et al. 2021). Also, it could be interconnected with other variables, but the most common statement around financial arrangements is that they are one of the biggest variables that affect the planning, implementing, and monitoring of NBS (Midgley et al. 2021; Martin et al. 2021; Palomo et al. 2021). In developing countries, it has been found that lack of resources and capacity and the need to provide multiple environmental and socio-economic benefits is one of the biggest barriers to NBS (Midgley et al. 2021).

2.4.2 Policy framework

The variable of policy framework refers to the legal conditions and presence of interest and pressure groups that influence the development of projects that include NBS (Martin et al. 2021). Different plans, programs, and legislations can be both a barrier as well as an enabler of NBS depending on the concept because these policy figures can promote the concept or not (Ershad Sarabi et al. 2019). "Politically effective strategies that, for instance, mobilize public and interest group support will expand the range of ways society can deploy technologies and reduce environmental harms." (Meckling and Karplus 2023, 1). But, in the case of NBS, we still don't have a specific legal condition or regulations that focus entirely on these interventions (Ershad Sarabi et al. 2019). Some aspects that are also considered as a part of the policy framework that

influences the effectiveness of NBS are land tenure, systems of ownership, empowerment, and overall access to land (Woroniecki et al. 2023).

2.4.3 Contextual preconditions

Implementing NBS is a complex process that implies understanding the social and cultural dimensions that can act as a barrier or enabler of NBS (Dushkova and Haase 2023), we are going to refer to these social and cultural dimensions of an SES as contextual preconditions. Contextual preconditions influence the effectiveness of NBS because adapting the NBS planning, implementing, and monitoring activities to the socio-ecological and institutional context is key for improving the probability of NBS achieving its goals (Dorst et al. 2019). Examples of these contextual preconditions are people's education level, poverty, institution capacities, historical institutions' values, and others (Woroniecki et al. 2023). The education level of a community is a variable that is included in the NBS literature because it can support the implementation of NBS or stop it completely (Woroniecki et al. 2023), but education level does not refer only to formal education but also knowledge about NBS, "Lack of information, or the uncertainty regarding NBS implementation processes and benefits, is frequently mentioned in the literature as a critical barrier limiting the uptake of NBS by decision makers." (Ershad Sarabi et al. 2019, 9).

Contextual preconditions that affect NBS effectiveness also include biophysical conditions of a place, awareness of environmental impacts, issues with grey infrastructure, presence of pressure groups, social norms that can promote collaboration and trust, cross-sectoral collaboration on other issues not related to NBS, expertise among stakeholders and community, existing interventions in the issue that the NBS wants to target, clearly identified problem and defined goals,

communication channels between stakeholders and community, land tenure, existing social conflicts and vulnerability (Martin et al. 2021). This variable also includes the ecological context of NBS, understanding the ecosystems that NBS are trying to contribute to is essential for its effectiveness (Dushkova and Haase 2023).

2.4.4 Stakeholder participation and collaboration

Implementing NBS in any context inherently impacts several actors and stakeholders (Dorst et al. 2019) So it is relevant to include a collaboration variable in the analysis of NBS effectiveness. Generally, collaboration is an important concept for environmental projects because it affects the achievement of goals and improves the commitment of local communities to change (Zurayk et al. 2001) And NBS are not the exception. Citizen involvement, inclusion, and considering perceptions and experiences of local communities are key for NBS effectiveness and the generation of multiple benefits because they improve the actions that tackle several issues at the same time (Ferreira et al. 2020; Palomo et al. 2021; Dorst et al. 2019; Martin et al. 2021). Also, a consequence of collaborative approaches is the enhancement of environmental stewardship and sense of place in local populations, especially in vulnerable groups (Ershad Sarabi et al. 2019). Collaborating with the local community since the early stages ensures that the NBS is contextually appropriate, improves trust between actors, empowers the community, and achieves goals (Dushkova and Haase 2023).

Collaboration also includes including local knowledge in the development of NBS, this strengthens the commitment of the local community to the NBS actions and improves the effectiveness of the intervention (Woroniecki et al. 2023). But collaboration for NBS is not exclusive to the local

communities, it also involves collaboration between sectors, scales, institutions, and authorities (Ershad Sarabi et al. 2019; Dushkova and Haase 2023). When different sectors collaborate it improves the results of an NBS because more actors split the responsibilities and they can rely on each other, for instance with a project that needs additional legal advice or additional unforeseen funding (Dorst et al. 2019). Nevertheless, these shared responsibilities could be a barrier to NBS because when different institutions or different departments of the same institutions are not working in harmony to tackle different dimensions of the same goals related to the NBS it could have a detrimental effect on the effectiveness of said NBS (Ershad Sarabi et al. 2019). Another form of collaboration that improves the effectiveness of NBS is the cooperation between the NBS goals and local political and planning objectives (Mell, Clement, and O'Sullivan 2023), which implies the creation of partnerships between actors to share the interests of the NBS and the planning objectives (Ferreira et al. 2020) and the integration of different authorities to tackle the same problem (Martin et al. 2021). Different authorities also include different scales, and scales could be temporal, spatial, institutional, jurisdictional, networks, and management (Midgley et al. 2021). Multiscale and multitemporal perspectives are also essential to NBS effectiveness because if the benefits of the NBS reach different scales it is more probable to achieve SES transformation (Sekulova et al. 2021; Midgley et al. 2021)

Collaboration in the NBS literature could also be interpreted as a source of positive outcomes in the community, not only a requirement for NBS effectiveness (Mell, Clement, and O'Sullivan 2023). For example, when NBS implements collaborative approaches and involves the community as an active actor it can improve the capacity of the community and the education level (Martin et al. 2021; Palomo et al. 2021). One way of achieving this is by providing training to community

members to perform activities associated with the NBS, this enhances the socio-economic levels of the community and the support of the community toward the NBS, also an important condition for NBS effectiveness (Martin et al. 2021; Ershad Sarabi et al. 2019). “Education, capacity building and multiple stakeholder involvement with initiation of multi-stakeholder dialogue during planning, implementing and operating of NBS is also very important for successful NBS implementation.” (Mori et al. 2023, 3).

2.4.5 Monitoring, communication and acceptance

Monitoring is an essential component of any environmental intervention and the NBS field is not the exception (Chrysoulakis et al. 2021). Monitoring activities ensure that NBS provides the benefits it promised, goals are achieved, improves impact, and facilitates learning (Chrysoulakis et al. 2021). NBS monitoring also involves a collaborative approach, which at the same time improves the relationship between actors and informs the decision-makers about the development of the interventions and their efficiency (Ershad Sarabi et al. 2019). As we mentioned before, NBS effectiveness needs to monitor and measure the impacts of NBS with indicators (Mell, Clement, and O’Sullivan 2023) However, there is little consensus in the literature about the ideal methods (Palomo et al. 2021).

Monitoring alongside communication and acceptance of the NBS are also enablers of NBS (Mell, Clement, and O’Sullivan 2023; Martin et al. 2021). Communication involves sharing information about the needs for contextual certain NBS, its requirements for effectiveness, and the benefits it provides (Mell, Clement, and O’Sullivan 2023) and depending on how the information about the NBS is shared, it influences the general acceptance of the NBS (Dushkova and Haase 2023; Martin

et al. 2021; Ershad Sarabi et al. 2019; Mahmoud et al. 2021). Likewise, the perceived effectiveness of NBS is essential because if a project is not accepted by the community it could lead to conflicts and barriers to the project development (Dushkova and Haase 2023; Martin et al. 2021; Mahmoud et al. 2021). Acceptance involves different actors and stakeholders such as investors, consumers, and companies that influence the implementation of the NBS (Dushkova and Haase 2023). Another perspective found in the literature is that in turn, working with the community in monitoring activities strengthens other efforts toward collaboration, improving trust between the NBS and relevant actors (Dushkova and Haase 2023; Lupp et al. 2021).

2.4.6 Social justice and equity

A current criticism of NBS that is considered important for this research is the report of case studies where NBS worsens social inequalities (Dushkova and Haase 2023) by providing benefits to only one sector of an SES (generally privileged neighborhoods or communities), one way of creating this with promoting access to green areas with payments or certain affiliation methods (Turner et al. 2022). This is why NBS needs a collaborative approach throughout the entire process of design, implementation, and monitoring (Dushkova and Haase 2023), so the promotion of social equity becomes a goal of the NBS and can improve the original conditions of inequality (Cousins 2024). However, the promotion of social equality and justice with NBS is a topic not very explored (Mell, Clement, and O'Sullivan 2023). Another take on this issue is a criticism of the focus of NBS on economic growth and creating private profit (Santiago Fink 2016) because by prioritizing economic income NBS usually ignores social justice change in an SES (Sekulova et al. 2021). So it is essential to NBS research to ask who makes the decisions in NBS projects and who receives

the benefits so that instead of deepening the privileges and gaps of a city it can achieve equity (Sekulova et al. 2021; Bremer et al. 2021).

2.4.7 Strategic Management Cycle

Another concept that is relevant to answering the research questions is strategic management, which involves a cycle of planning, analyzing, and implementing certain actions (Lucas 2010). The cycle consists of identifying the goals, analyzing the abilities to achieve the goals, creating strategies, and then evaluating the effectiveness of the strategies and starting again (Lucas 2010). This is relevant to NBS because management that is focused on monitoring the impacts of the activities, learning from it, and changing the course of action to achieve certain objectives is necessary to increase NBS's effectiveness (Ershad Sarabi et al. 2019; Sowińska-Świerkosz and García 2022). There are many different illustrations of the strategic management cycle in the academic and grey literature, one version shown in Figure 1. This version by Warren and Lulham (2021) was selected because besides the stages of the process, it also highlights the central importance of stakeholder collaboration and the role of institutions and policy arrangements. These have been widely recognized in the literature for their contribution to NBS effectiveness and embeddedness in urban SES.

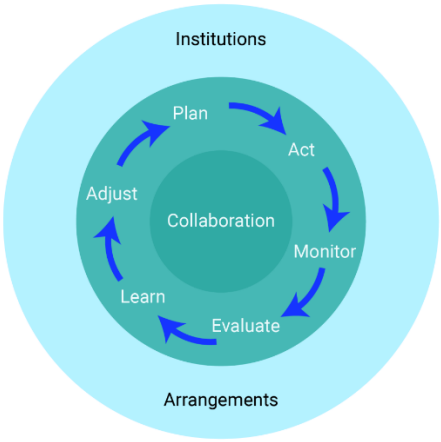

Figure 1. Diagram explaining the adaptive management cycle. source: (Warren and Lulham 2021)

2.5 Water-related NBS

A relevant set of NBS that will be highlighted in this research are the ones related to water issues. NBS that are commonly used to address water-related issues could be planted permeable pavements, green roofs, green walls or facades, rain gardens, bioswales (channels for rainwater runoff), ponds, artificial wetlands, river channel restoration, and others (Tsatsou, Frantzeskaki, and Malamis 2023). Their main objective is to solve problems that include water pollution, water availability (related to droughts, flooding, and decrease in rain), weak wastewater management systems, poor urban drainage (WWAP (United Nations World Water Assessment Programme)/UN-Water. 2018; Acreman et al. 2021), and according to research such as the one performed by Acreman and colleagues, water-related NBS are known to produce direct positive impacts on water and climate (2021). Including efficient water collection for public use or agriculture, reducing high temperatures, draining rain and flood water, replenishment of subterranean water sources, improvement of water quality, and erosion control (Acreman et al. 2021; Chen et al. 2022). Another reason why water-related NBS are relevant for this research is because of their ability to produce social benefits (Oral et al. 2020). Oral and colleagues suggest

another classification for water-related NBS that comprises three categories "stormwater management, water-food-energy nexus using water for food and energy production and water pollution control." (2020, 17).

2.6 City of Cartagena de Indias

The city of Cartagena de Indias is located on the northern coast of Colombia, next to the Caribbean Sea. According to the National Administrative Department of Statistics (DANE), the city has a population of 1.013.389 inhabitants, making it the fifth most populous city in Colombia (DANE 2020). Cartagena is the third capital city with the highest economic activity in the country due to the boom of three economic sectors: industry, tourism, and port activity (Valdés Valencia, Friedrich-Ebert-Stiftung in Kolumbien, and Foro Nacional Ambiental 2017). Cartagena is one of the cities with the most historical values in the country, due to its strategic location it was the most important port of the Caribbean during the 16th, 17th, and 18th centuries, it was a link in "world exploration" and commercial maritime routes, and it conserves colonial infrastructure of complete systems of military fortifications, walls, religious and residential monuments (UNESCO World Heritage Centre 2023). It is recognized as a UNESCO World Heritage Site. Cartagena also played a significant role in the transatlantic slave trade, which left an impact on its cultural fabric (Aguilera Díaz and Diaz 2009).

The city has an area of 623 km2, of which 76 km2 is urban and 547 km is rural, 96.6% of its population resides in the urban areas (Chica-Mejía et al. 2022). This situation creates complexities of habitability, mobility, concentrations of wealth, high poverty rates, and enormous inequalities among its inhabitants in the urban area of Cartagena (Chica-Mejía et al. 2022). Despite being one of the cities with the most economic activity, Cartagena is the third city with the most poverty in

the country, it registered monetary poverty of 32.7% in 2012, while for the average of the thirteen main cities that indicator was 18.9%, education levels are also low with only 13.6% of Cartagena's heads of household presenting completed university education, either undergraduate or graduate, with high inequalities (Valdés Valencia, Friedrich-Ebert-Stiftung in Kolumbien, and Foro Nacional Ambiental 2017). 31% of the population of the city lives in the La Virgen and Turística district, one of the areas with the highest rates of multidimensional poverty in the city, the population is mostly comprised by Afro-descendants and migrants (Valdés Valencia, Friedrich-Ebert-Stiftung in Kolumbien, and Foro Nacional Ambiental 2017). Cartagena presents a Gini coefficient of 0.45 (Figure 2) meaning that there is a significant level of inequality (DANE 2020).

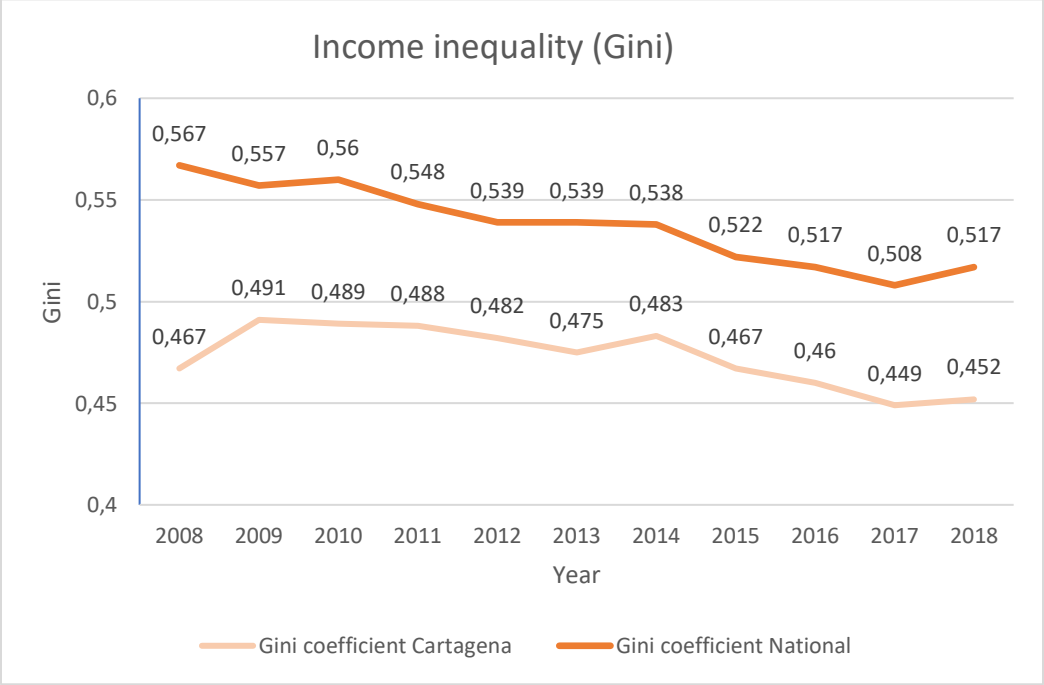

Figure 2. Gini coefficient of Cartagena and Colombia since 2008 to 2018. Source: Adapted from (DANE 2020).

The city of Cartagena is surrounded by a system of canals and internal lakes (Laguna de San Lázaro, Ciénaga de Las Quintas, Caño Bazurto, among others) that occupy 93 hectares and 9 km, that communicate the Ciénaga de la Virgen and the Bay of Cartagena at the ends of the system,

which are directly influenced by the Sea Level Rise (Cañate, Guzmán, and Mouthon 2018). The system of canals and lakes can be observed in Figure 3.

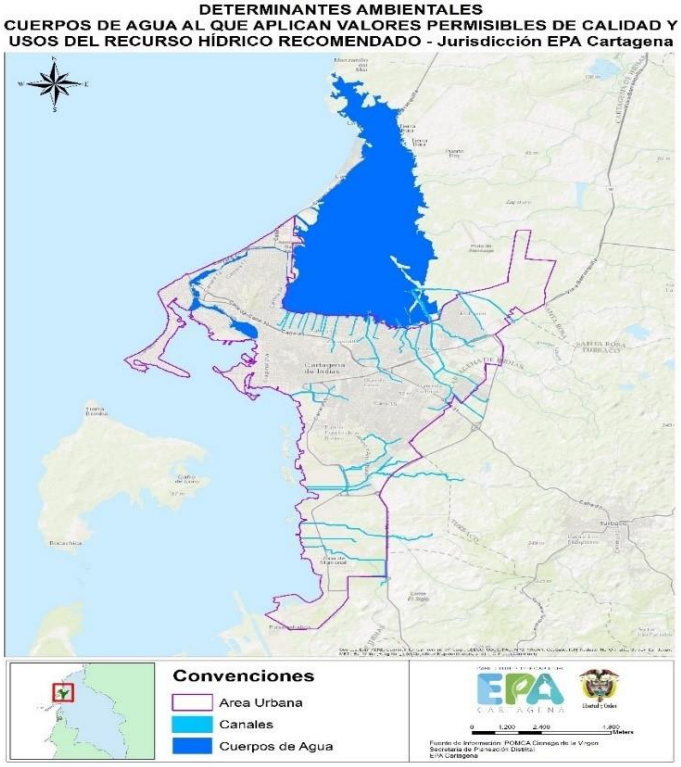

Figure 3. Map of Cartagena in pink lines and the water bodies from the system of canals and lakes in blue lines. Source (EPA Cartagena 2021a)

In conclusion, this literature review focuses on the description of NBS, the input of different authors to the different definitions and classifications, and case studies with different applications of said concepts. It also reports some of the most relevant concepts that influence NBS effectiveness, and it reflects the gaps that currently exist in NBS literature and that it will take several years to close, for instance around the topic of identifying how to understand the impacts of NBS monitoring and global indicators of success. On the other hand, it also shows the general improvement of the definition in recent years, the importance of water-related NBS and it demonstrates how the NBS sector is currently growing and working toward better results.

3. Theoretical Framework

The theoretical framework was built using the concepts from other authors who explain how NBS can be affected by factors, enablers, barriers, or mechanisms associated with the context of the community, the governance arrangements, and many other characteristics of an SES (Turner et al. 2022; Phuong, Biesbroek, and Wals 2018; Ershad Sarabi et al. 2019; Ostrom 2009). For this research, I am going to classify these concepts into internal factors, external factors, and management variables according to the diagram in Figure 4.

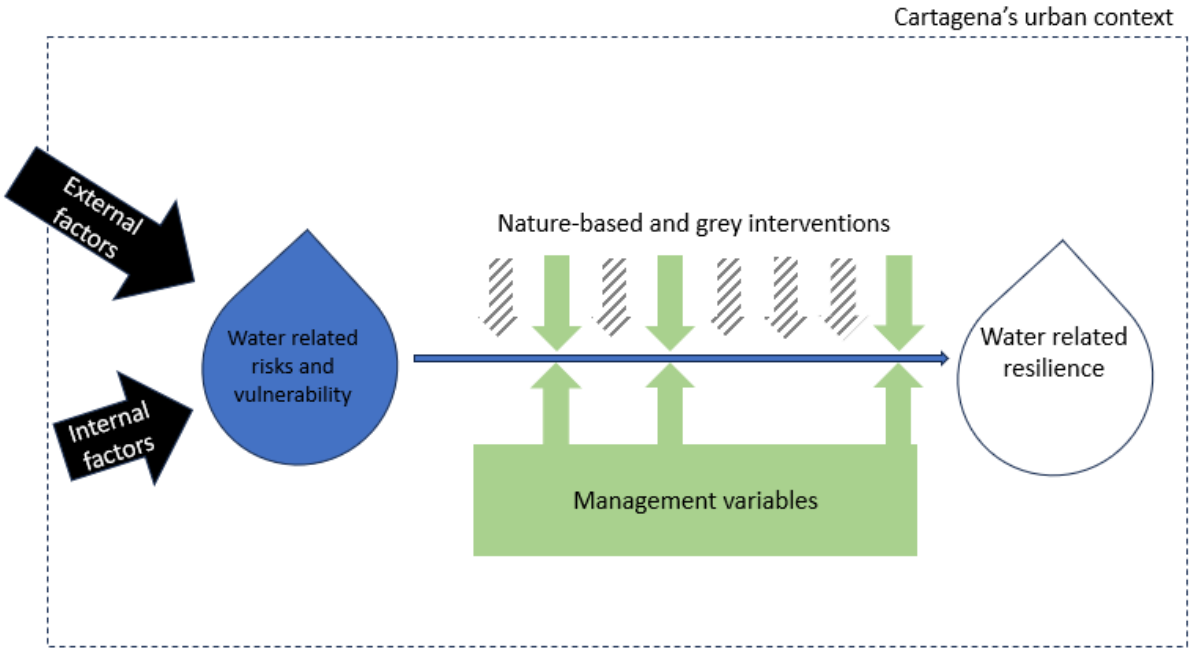

Figure 4. Theoretical framework. Source: author.

In the diagram, it can be observed that within Cartagena's urban context, there are external and internal factors that directly influence water-related risks and vulnerabilities. Risk is defined as "The potential for adverse consequences for human or ecological systems" (Reisinger et al. 2020,

4), and vulnerability is understood as "the state of susceptibility to harm from exposure to stresses associated with environmental and social change and from the absence of capacity to adapt" (Adger 2006, 1). These water-related risks and vulnerabilities present in Cartagena could be addressed by NBS and grey interventions (green and lined arrows) and management variables, the concepts that were found during the research literature and interviews. The management variables are associated with direct interventions classified as NBS. Overall, the internal and external factors, the presence of NBS, grey infrastructure, and management variables have the potential to influence water-related risks and transform them into water-related resilience.

The limitations of this framework are associated with the fact that it was designed with academic literature specifically for this research, and it could be challenging because there is not a frame of comparison or reference to the analysis and expected results. It also includes a big level of complexity, associated with the dynamics found in any city around the world, but at the same time it might not include relationships between different factors because is out of the scope of the goals of this thesis, and it includes concepts that are difficult to quantify, which could complicate future applications.

4. Methods

In this chapter, I will describe the research approach that helped me achieve my research goal and answer the research questions. It includes justifications with academic literature and a statement on research ethics. The limitations of the research will be included in chapter 7, conclusions and recommendations.

4.1 Methodological approach

The approach used to answer the questions of this research involves qualitative methods, gathering primary data through interviews and surveys, secondary data from the literature identified through a search strategy, and the use of academic search engines such as Google Scholar and Scopus and provides insights to perform a thematic analysis based on the concepts included in the literature review. Qualitative research is appropriate for this thesis because it represents an exploratory approach to analyzing phenomena and their meaning for relevant actors (Williams and Moser 2019).

The first step before collecting primary information was identifying relevant water-related NBS in Cartagena and relevant actors. This step was developed through Google searches with keywords involving the types of NBS included in the EU Horizon 2020 NATURVATION PROJECT and the words “Cartagena de Indias”, the result was a non-curated database with 30 potential NBS. In order to define the NBS to be interviewed another step was taken, I reached out to the organizations in charge of the NBS querying if they would be interested in participating in my research and if they would have time available for an interview and a visit. Of the original 30 water-related NBS, only 17 were selected. After the organizations were reached out, seven interviews and visits were carried out in the city of Cartagena. The interviews were conducted in Spanish, with the person in

charge of the NBS, and the analysis of the codes and themes was performed in English. The different databases were stored in Excel spreadsheets and the selected NBS were organized depending on the actors in charge, their goals, their stages, the amount of information online (websites, documents, research), and their responsiveness to my contact attempts.

The water-related NBS that were included in the research are shown in

.

Number	Project	Entity in Charge
1	National Natural Park Corales del Rosario y de San Bernardo	Colombia National Natural Parks
2	The recovery project of La Ciénaga de la Virgen	EPA Cartagena, The Environmental Public Establishment (the maximum environmental authority in the area)
3	Recovery plan for the Juan Angola River	EPA Cartagena, The Environmental Public Establishment (the maximum environmental authority in the area)
4	Urban Forestry Plan for Cartagena - Urban reforestation, planting and maintenance program	EPA Cartagena, The Environmental Public Establishment (the maximum environmental authority in the area)
5	Master Plan for the Ecological Restoration of the Bay of Cartagena	EPA Cartagena, The Environmental Public Establishment (the maximum environmental authority in the area)
6	Research project in Urban Park Lácides Segovia	Biontessori Research Group of the Montessori School of Cartagena, led by Professor Juan Felipe Restrepo.
7	Water as Leverage	several actors - Ministry of Infrastructure & Water Management of the Netherlands

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Table 1. NBS Included in the research.

4.2 Secondary data search.

To identify the internal and external factors that influence the planning, implementation, and monitoring of NBS, I reviewed academic literature that reports research on NBS. The articles were found with the Google Scholar database, SCOPUS, and the Central European University (CEU) Library, which includes JSTOR, Science Direct, and Project Muse. To collect information about the specific projects and NBS in Cartagena I reviewed grey literature (legal documents, publications, websites, reports, etc.) to understand the background and context of each project. These documents are considered secondary sources because they are reports of data that I, as a researcher, have not experienced directly, and because I am using them to verify findings based on other information (Merriam and Tisdell 2016).

The main search term involves a combination of "Nature-Based Solutions" with terms that were interesting to me and that were common in the literature. These terms were "management",

“collaboration”, “networks”, “socio-ecological systems", “resilience”, “education”, “citizen science”, “government plans”, “water”, “Colombia”, “Cartagena”, “coastal”, among others.

4.3 Interviews and Surveys

The primary information was collected using surveys and interviews with the professionals in charge of the selected NBS. In total seven interviews were performed and transcribed in Spanish. The process of the interview had a duration of approximately 1 hour, I started by introducing myself and presenting my research, as shown in Annex I and II, with the interview protocol provided by CEU, and then I explained the use of the interview data and agree on anonymity, asked for verbal consent to be recorded and then started with the survey and interview questions.

The questionnaire was divided into six sections (Annex I and II), the first section asked questions about the personal information of the interviewee (I), and the second section covered survey questions about the NBS (II), to confirm that the professional provided the same information found online. The following sections included a survey and open-ended questions about the planning of the NBS (III), followed by another section on the implementation of the NBS (IV), monitoring (V), and overall results (VI). The purpose of including different types of questions was to corroborate the official information of the projects and gather personal opinions and perspectives of the people involved in the NBS, information that can’t be found in official sources.

Semi-structured interviews were selected as a tool for this research because they provide an in-depth understanding of other people's experiences and opinions (Seidman 2006), in this case, they provided valuable information about living and working in Cartagena and tackling challenges that

have been present for decades. As the author Irving Seidman said, “It is a powerful way to gain insight into educational and other important social issues through understanding the experience of the individuals whose lives reflect those issues (2006, 24).

The interview questions were complemented with survey questions in case the conversation did not flow naturally toward the information I needed. The main purpose of the survey questions was to obtain accurate information about the NBS since this tool is “intended to systematically describe the facts and characteristics of a given phenomenon or the relationships between events and phenomena” (Merriam and Tisdell 2016, 29).

The selection of potential interviewees was executed with expert consultation, purposive Sampling, and Snowball sampling. The expert consultation was performed by exchanging emails with professionals from the mayor’s office in Cartagena and the University of Cartagena and then when the fieldwork started with short meetings. Purposive sampling is a tool used in disciplines such as ethnobotany, and it consists of selecting potential interviewees depending on their qualities and knowledge (Tongco 2007). In my case, the qualities were experience in the water sector of Cartagena and work experience in decision-making processes. Snowball sampling was used to complement what was previously mentioned, and it consisted of asking the interviewees to refer me to other potential sources of information (Merriam and Tisdell 2016). in my case, I would ask for other projects and NBS relevant to the water sector of the city.

4.4 Analysis.

The analysis of the interview's transcripts was performed with thematic analysis, an organizing structure for qualitative data that consists of selecting codes (words or short sentences) that assign attributes to language (Williams and Moser 2019). This process has been used to categorize data and create theory (Williams and Moser 2019). The process for coding interviews is three non-linear steps: open coding, axial coding, and selective coding (Williams and Moser 2019). The first step, open coding, consists of assigning codes for emergent themes or concepts by organizing similar data from different sources, the second step is axial coding, and this implies identifying relationships between the codes to create core codes for the data or categories, "In open coding, themes are being developed" (Williams and Moser 2019, 8). The last step, selective coding, consists of selecting the main codes that tell the story we are trying to understand, this means selecting the main codes or thematic categories and illustrating causality or predictability, this step allows the researcher to build theory (Williams and Moser 2019). Additionally, the codes were also analyzed by the strategic management cycle concepts and steps presented in the literature review.

The first step resulted in over 200 codes divided into 12 categories of codes that include topics such as education, goals definition, institutional collaboration, environmental awareness, multiscale collaboration, social issues, land planning, public and mixed funding, and others. These categories were organized by themes, which are the variables included in the discussion, top-down governance, collaboration, funding, political continuity, monitoring, communication, education and capacity building, and water focus. It was decided that these themes represent the story of the design, implementation, and monitoring of NBS in Cartagena, Colombia.

4.5 Ethical statements.

Following the ethics guidelines from CEU, I asked each interviewee for verbal consent for the recording, storage, and analysis of the interview and the information it provided, I informed them about their voluntary participation, the possibility of withdrawing and removing their interview from my research, and their right to privacy. All interviewees gave verbal permission for me to use their names and occupations, nevertheless, the name of the participants is not included in the documents. I, a Colombian student enrolled in the Master of Science in Environmental Sciences and Policy at Central European University in Vienna, Austria, performed all the interviews included in the research. CEU required an ethics form consisting of a Checklist on Ethical Issues in Research which was filled in by me and approved by my thesis supervisor and the Department of Environmental Sciences and Policy.

5. Results

This chapter will cover a summary of each of the interviews performed with the seven NBS, which do not involve Nature-Based Solutions exclusively, but plans, projects, and programs from private and public institutions that involve NBS intervention in combination with other strategies. The first interview described corresponds to the National Natural Park Corales del Rosario y de San Bernardo, followed by the Urban Forestry Plan for Cartagena - Urban reforestation, planting and maintenance program, the Recovery project of La Cienaga de la Virgen, Recovery plan for the Juan Angola River, Master Plan for the Ecological Restoration of the Bay of Cartagena, Research project in Urban Park Lácides Segovia, and Water as Leverage. This chapter answers the first research question (What are some of the key water-related challenges in Cartagena?), the second

research question (What are some prominent examples of water-related NBS?), and the third research question (What do we know about their implementation strategies and effectiveness?) because it will describe the most relevant aspects related to the management of water-related NBS in Cartagena.

The key water-related challenges of Cartagena found in the literature are typical anthropic and climatic threats that impact its marine and coastal ecosystems (Uribe et al. 2022), environmental risks associated with climate change, such as rising sea levels and increased rainfall, which have a significant social and economic impact, since a large part of Cartagena's population lives in the coastal zone and the city's main economic sectors are located near the sea (Valdés Valencia, Friedrich-Ebert-Stiftung in Kolumbien, and Foro Nacional Ambiental 2017). Figure 5 Shows the sea level rise measured between 1949 and 1992 and the estimated tendency.

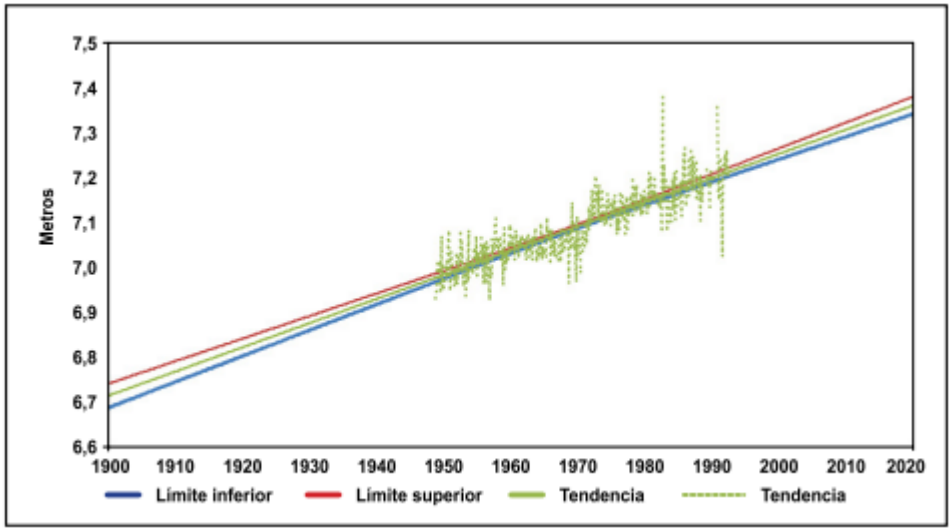

Figure 5. Data and tendency in sea level rise. Source: (Valdés Valencia, Friedrich-Ebert-Stiftung in Kolumbien, and Foro Nacional Ambiental 2017).

Cartagena has transformed the landscape, beaches, marshes, and mangroves have been transformed into an urban conglomerate (PNNC 2020), but urbanization is not always legal, illegal occupation of land around water bodies such as Cienaga de la Virgen has been a phenomenon reported for years (Richerzhagen et al. 2019). Also solid waste and wastewater management is a constant issue creating problems related to pollution to the system of channels and lakes of the city (Richerzhagen et al. 2019).

Other water-related problems are detailed in every NBS case below.

5.1 National Natural Park Corales del Rosario y de San Bernardo

The National Natural Park Corales del Rosario y de San Bernardo is a protected area located in the Colombian Caribbean, within the jurisdiction of the city of Cartagena (PNNC 2020). It comprises around 120,000 hectares of marine ecosystems, islands, mangroves, seagrass beds, and the largest coral platform in the country (PNNC 2020). It also has relevant social and ecological functions as it contains several indigenous and Afro-Colombian communities and native biodiversity (PNNC 2020). Figure 6 shows a map of the protected area in green and the city of Cartagena in the northeast.

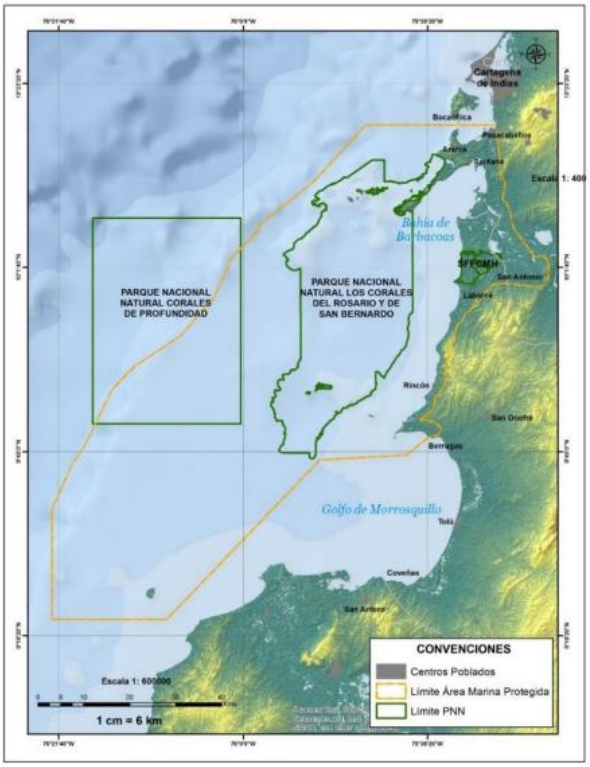

Figure 6. Location of the National Natural Park Corales del Rosario y de San Bernardo. Source (PNNC 2020).

The national park was included in this research because of its ecological restoration activities and because it is influenced by the activities of the city of Cartagena. Currently, some of the problems affecting the park are water pollution from the channels of the city and port activities, poor water management from the communities because of poor infrastructure, shrimp farming, agriculture, boat transportation, overfishing, illegal tourism activities, and climate change (PNNC 2020). Climate change could cause increased rain, storm surges, increase in heatwaves, water temperature rise, and other impacts that affect the socioecological system of the city and the park (PNNC 2020).

Primary data was collected via an interview with a professional in charge of monitoring the park.

At the moment the park is formulating new restoration projects, and the last project was a national initiative executed by an international NGO. All the projects designed and implemented by the park are funded by the national government, so they depend on the national development plans and budget, which means that every project lasts around 4 years. Because of the collaborative approach implemented in the park's management plan (PNNC 2020), every project must include community members in all their stages, "this project was done with some strategic allies, foundations, the communities, with the community councils, with the Afro communities that we have in the park, we hired, some of the leaders from the communities to be the ones to carry out the development, to be the gardeners of the nurseries of the coral restoration"(National Natural Parks professional, 2024). The participation of the community includes collaboration during the identification of priority restoration activities, to the hiring of local people to build the structures for the coral.

Most restoration projects include an environmental education and environmental awareness component, in this case, they are planning to incorporate awareness programs about the services of coral reefs and mangrove forests. A situation reported during the interview was the identification of a clear problem during the formulation of the restoration project. The park professionals identify the needs and threats in the protected area and create social, environmental, and economic goals and objectives accordingly. They also include the target beneficiaries of the restoration efforts, which are normally the local communities, the city, and the biodiversity that relies on the protection of the ecosystems involved.

Besides the work with the community, the restoration projects also prioritize collaboration with other organizations such as private research centers, foundations, and NGOs, and explain that this collaboration is essential to the fulfillment of the conservation and management goals and that their help is key for the daily activities of the park. Within the collaboration agreements, the other organizations provide personnel and their working hours, materials to build the infrastructure, transportation, and others. Private companies can also make donations to the park administration.

The monitoring activities are also very central to the park's objectives but due to the limited funding available, they are not covering enough information. For instance, one project that finished last year and was a national initiative did not include monitoring after the project's completion, this hinders the conservation efforts and makes it impossible to state if the projects work or not. Also, the funding does not cover the amount of information that needs to be collected in order to be statistically significant. Also, the monitoring information should be in the public domain and be shared on online public platforms such as the ones from the Marine and Coastal Research Institute (INVEMAR) website. However the information available is not up to date and it is unknown by the professional interviewed how much time it takes for the information to be published.

5.2 Urban Forestry Plan for Cartagena - Urban reforestation, planting and maintenance program

"The Urban Forestry Plan for Cartagena, coordinated by the EPA Cartagena, seeks, through the technical selection of species, planting and management, thermal attenuation through the shade, generation of microclimates, protection from climatic events (protection from coastal erosion, windstorms, etc.), food security for Cartagena and landscape embellishment, among many other

co-benefits that trees provide for the city" (EPA Cartagena 2017, 7). This plan aims, for the next 10 years, to consolidate a forest stand of at least 100000 trees in addition to existing trees in the city, increase effective thee cover, more accessibility of green areas, consolidate a main ecological structure based on the natural supply and trees to be established in the city, including biodiversity criteria as a guiding principle for the actions carried out, improve food security, recognition of local knowledge and prioritizing the use of local resources, and reduce heat island effect (EPA Cartagena 2017).

Primary data was collected via an interview with the coordinator of the Urban Forestry Plan.

According to the interview, the main objective of the plan is to orientate the planting of trees in the city of Cartagena with a list of desirable species and management and is planned to be permanently executed by the Environmental Public Establishment of Cartagena (EPA), the environmental urban authority. The plan is currently undergoing a reformulation to evaluate how appropriate the list of species is to the citizens, as well as the areas designated to certain species, but the planting activities have not stopped at the moment, the planting activities are called planting sessions. The process for requesting a planting session is the following: anyone from the city can request a session from the EPA as long as the location of the plants is public land (public spaces, sidewalks, parks, public transportation stations, public school grounds, streets, etc.), the EPA then visits the area and determines the ideal species to be planted, they provide the plants, tools, and manual labor. Depending on the case the EPA requests support from other public and private institutions for the planting sessions and the funding comes from public sources such as the compensation activities of companies with environmental licenses. After the planting, the citizen

who requested the session has the responsibility of maintaining the plants and the EPA conducts monitoring, but the monitoring activities are not structured. Every planting session is georeferenced and reported on the website.

Alongside the planting session, the department of the EPA in charge of environmental education performs environmental awareness sessions with the community that receives the trees about the importance of taking care of urban biodiversity. A relevant element of the plan is the collaboration with different institutions such as Pacaribe, the company that provides public sanitation services to more than 55% of the city's population. When there is a planting session in a place with waste pollution, Pacaribe does the waste collection with the support of the EPA and then the planting session takes place. Some companies also donate trees and tools for the sessions and collaborate with manual labor.

According to the interview the plan was formulated with a clear problem in mind because citizens were planting invasive species without information, and it targets the entire city, under the jurisdiction of the EPA. Also, the plan collaborates with other plans in the city and restoration efforts, for instance for the Recovery project of La Ciénaga de la Virgen (discussed in another section) the urban forestry plan provides plants and guidance on ideal species of mangroves. Another important element of the plan is communications, they are constantly sharing on social media about the planting sessions, sharing relevant information, and inviting the community to be a part of the initiatives.

During the fieldwork, I visited a public school where the EPA was implementing a planting session (Figure 7) and also a park that is located around and water body and is currently undergoing renovation and received mangrove plants for the land cover (Figure 8).

Figure 7. Pictures of planting session in public school. Source: author.

Figure 8. Pictures of public park with planted mangrove from the Urban Forestry Plan of Cartagena. Source: Author.

5.3 Recovery project of La Ciénaga de la Virgen

The Ciénaga de la Virgen is a coastal lagoon located on the north side border of the city of Cartagena and separated from the sea by La Boquilla sandy beach, it has a maximum width of 4.5 km, a length of about 7 km, a water body of about 22.5 km2 and depths of up to 1.6 m. It is

connected to the system of canals and internal lagoons of the city through the Juan Angola channel. On the eastern side, there is an area of mangroves and swampy areas covering an area of 7.5 km2 (EPA Cartagena 2015a). In Figure 9 You can see the cienaga in yellow and the city limits in pink. La Cienaga de la Virgen is the second biggest coastal lagoon of the Colombian Caribbean and an important condition of the cienaga to take into account is the presence of marginalized communities (Chica-Mejía et al. 2022). The origin of the marginalized communities of the cienaga is the illegal occupation on the urban edge of the water bodies by mainly displaced afro-Colombian population (Chica-Mejía et al. 2022). The main problems of the cienaga are produced by illegal waste dumping, pollution by wastewater from illegal houses and also by fraudulent sanitary sewer connections, oil and hydrocarbons from garages and service stations located in the urban watershed, and garbage and solid waste dumped by some inhabitants of the adjacent community (Chica-Mejía et al. 2022; EPA Cartagena 2015a; Maldonado, Baldiris, and Díaz 2011).

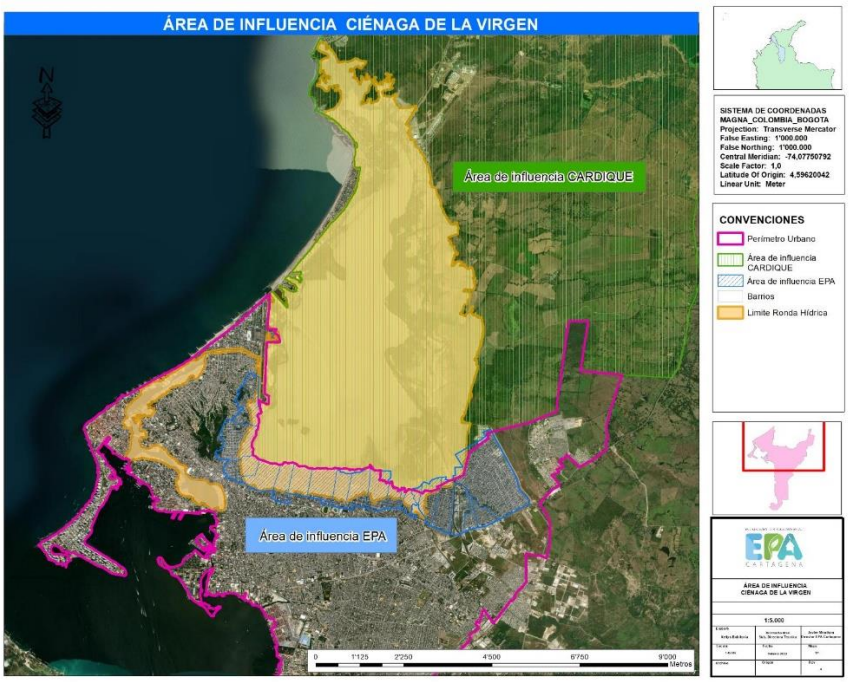

Figure 9. Map of Cienaga de La Virgen in relation to the city of Cartagena. Source: (EPA Cartagena 2022).

Primary data was collected via an interview with the former coordinator of the Recovery Project of La Cienega de la Virgen. The main findings are described below.

The recovery project of la Cienaga de la Virgen, in charge of the EPA Cartagena, consists of seven main activities that are aimed at the protection and restoration of the Cienaga. The project has a participatory approach, in several stages, they have implemented what is called “mesas de governance” or governance tables where governmental and private entities, community actors, academia, environmental NGOs, and other participants with an interest in the improvement of the ecosystem. One of the main activities is stopping the illegal occupation of the cienaga, improvement of the roads connecting the neighborhoods, relocating people, reforestation, strengthening social participation, wastewater management plans, proper operation of the tidal stabilization system of La Bocana (an artificial channel that allows a controlled exchange of water

between the cienaga and the sea), which includes dredging and cleaning in areas of the cienaga, and others.

A special situation of the cienaga is the shared jurisdiction between the urban authority (EPA), and the regional authority "Regional Autonomous Corporation of the Canal del Dique" (Cardique), since it is located on the border of the city, the EPA has jurisdiction as long as there are houses but the actual water body is under the jurisdiction of Cardique. So, every action has to be coordinated with them. Just like the other projects, the recovery plan is on hold because it needs new authorizations from the mayor's office and the new development plan. But at the moment is it planned to be a permanent project until the goals are achieved. The funding for the project is mainly public, coming from the city, but private donations of materials are an important source for the activities too.

The project, besides including restoration and physical interventions with grey infrastructure, also has a strong educational component. It includes environmental education about pollution and management and about possible economic sources for the community such as recycling companies and mangrove nurseries that become the main source of income for local families. In the context of the project, they also perform monitoring of the water quality and mangrove forest around the cienaga, but the publication of the information is not finished, according to law, the information should be published on the EPA websites. Some activities are also supported by NGOs and private companies, for instance when they are building fences some foundations collaborate with material and manual labor.

The project also collaborates with other plans from the EPA that target the same neighborhoods around the cienaga, for instance with the "Barrios Sostenibles" program, (sustainable neighborhoods) they worked together in solid waste collection sessions and the result was an alliance between recycling centers and the community. From the recovery project itself, new projects have emerged, such as the creation of a protected area from the restored mangrove forest. These projects would work synergistically in the area, but the new project has no funding. Another project that was born was the design and implementation of solid waste traps which consist of nets that stop the waste from flowing into the water and then be collected by the community.

According to the interviewee, even though the project was stopped it already produced some positive impacts in the community. Some initiatives for the children and youth of the community involve the creation of music centers, gardening groups, solid waste collection sessions, and overall, an improvement of the environmental awareness of people, who now understand that to improve their life quality they need to provide better conditions for the ecosystem and stop the population growth around the cienaga. Also, the interviewee highlights the importance of including the community in every stage of the project because the success of the efforts relies mostly on their collaboration.

A visit to the Cienaga de la Virgen was not possible due to security issues but the EPA Cartagena provided the next pictures (Figure 10) and a story maps with detailed map images:

Figure 10. Pictures of Cienaga la Virgen and activities performed by the EPA. Source: EPA Cartagena

5.4 Recovery Plan for the Juan Angola River

The Juan Angola River is part of the system of rivers and channels of the city of Cartagena, and it connects the Ciénaga de la Virgen and the Bay of Cartagena and faces similar issues as Cienaga la Virgen such as illegal occupation of its borders, illegal waste dumping, deforestation of mangroves, and pollution (EPA Cartagena 2021b). The recovery plan for the Juan Angola River is in charge of EPA Cartagena, and it consists of relocating families, eliminating the Benjamín Herrera bridge, which with its piles or bases obstructs the current, and building another one in a wider area, recovering the low tide and riverbed areas, build pedestrian paths, clean and dredge, recover mangrove areas and initiate processes of education and environmental awareness in this sector (EPA Cartagena 2021b).

Primary data was collected via an interview with the coordinator of the water resource management projects at the EPA Cartagena. The main findings are described below.

The plan is the response to a legal requirement by the city of Cartagena, in this requirement there are several public institutions involved but the EPA oversees the coordination of the activities. Also, in the legal requirement collaboration with the community is essential so in every stage of the plan there have been collaborative spaces where the community manifests their priorities. And since the main problems present in the river are related to the community (illegal occupation, deforestation of mangroves), the plan also targets the cooperation between the daily activities of the community and the protection of the river, for that reason they implemented social cartography exercises. At some point there were conflicts with the community and the projects had to stop, reformulate, and integrate the community's demand. Additionally, the environmental education component of the plan is central to the EPA and to achieve their goals they are collaborating with local schools, foundations, community boards, and others with activities for an increase of environmental awareness and also support for entrepreneurial efforts in the local communities. Since the city just elected a new mayor, it is expected that the coordination of the plan will change from the EPA to a department of the mayor's office, so the project is currently on hold. Also, it is expected that some planned activities are going to change due to the new development plans of the city.

The plan is articulated with the Recovery project of La Ciénaga de la Virgen since the two water bodies are connected and are facing the same issues. The possible benefits of the plan are also

considered to have a multiple-scale effect on the immediate neighborhoods next to the river and the city overall. The funding of the activities comes mainly from public sources but also private companies such as Acuacar. This project is articulated with the city's land management plan which provides guidelines for the interventions in certain neighborhoods around the water body. In the plan, there is no monitoring included at the moment because the legal figure that establishes the activities in the river does not require direct monitoring of the impacts but that could change with the new administration and the development plan. However, the EPA performs monitoring of the water quality of the river under other responsibilities outside the plan. Additionally, there are conflicts with the land around the river because most properties are private, and Colombian law establishes that the strip of 30 meters around the water body is owned by the state.

Pictures of the river and some areas around it are found in Figure 11.

Figure 11. Neighborhoods around the Juan Angola River. Source: author.

5.5 Master Plan for the Ecological Restoration of the Bay of Cartagena

All the cienagas, rivers, and lakes of the city of Cartagena are connected to the Bay of Cartagena (EPA Cartagena 2015b). The bay is a water body located on the western border of the city, approximate extension of 8 km2 and an average depth of 20m (Figure 12) (EPA Cartagena 2015b). More than 50 companies and industries are located in the bay, during the last years its economic development has been increasing due to the increase in the number of ports and oil refineries, the main sources of pollution in the Bay Area domestic discharges due to population growth, industrial activities, ships transporting hydrocarbons, and human activities, another source of pollution is the extraction of metals that reach the bay by fluvial means, the authorities have detected heavy metals such as copper, mercury and nickel (Peña Mora 2022).

Figure 12. Location of the Bay of Cartagena (yellow letters). Source: (EPA Cartagena 2015b).

The master plan for the Ecological Restoration of the Bay of Cartagena is a document of technical guidelines that contain measures, actions, and projects that assist in the recovery and restoration of the ecosystems present in the bay, it consists of actions, organized in six programs, that tackle

the main problems of the bay by implementing preventive programs, strategic management, and a viable governance scheme that guarantees operational execution, decision making and community participation in the continuous recovery of the natural systems of this ecosystem (MinAmbiente 2022).

Primary data was collected via an interview with one of the professionals in charge of the monitoring programs in EPA Cartagena. The main findings are described below.

The first thing mentioned in the interview was that the master plan is currently on hold because of the transition of the new government, that the plan is a national legal requirement, and that its six programs come from national policies developed by the Environmental and Sustainable Development Ministry of Colombia (MinAmbiente). The plan requires the collaboration of different national, regional, and local institutions, and the EPA is in charge of developing certain activities in two of the plan's programs. Program 2 focused on restoration and 3 focused on conservation are the ones that were considered nature-based solutions, but the EPA is only involved in monitoring activities and collection and publication of the monitoring data. The ecological restoration activities involve coral reef restoration, mangrove restoration, and sea grass restoration with collaborative approaches, but the restoration efforts are in charge of Cardique, the regional authority.

"The Ministry is the one that coordinates all the actors, that is to say, they are the ones that summon the technical worktables, the community actors, fishermen, community councils, but also civil society and the Academy and representatives of companies or business associations" (EPA Cartagena professional, 2024).

Another relevant problem in which EPA is working with Cardique and Cartagena's Mayor's Office targets environmental education. The program seeks to collaborate with local schools and involve the children and youth of the community in the plan. Nevertheless, these programs have not been implemented yet, since 2021 the authorities have been building the plan alongside the community, the interviewee explains that the longer stage was the diagnosis for each program. The results of other programs that are articulated in the plan, such as coral restoration projects in the bay are not public yet.

A relevant aspect of the plan is the collaborative approach, the community has been present in the identification of the critical points in the bay, pollution sources, and the intervention and monitoring activities that are planned to be permanent. Nevertheless, the community's participation was not very strong in the earlier stages of the planning process. The funding of the plan is different from the other projects included in this research because every institution oversees funding their activities with their funding budget, the national ministry is not providing money, but they are supporting the plan by providing information and coordinating. The master plan is set to be implemented in five years, they are currently in the transition between the second and third year, but the opinion of the interviewee is that the plan is going to continue until the goals are achieved.

In the bay, there also exist private initiatives that are similar to the master plan goals but on a smaller scale, for instance, there are companies creating projects for their corporate responsibility programs that involve restoration and work with local communities.

Since the plan does not have any interventions in the bay yet I could not obtain pictures.

5.6 Research project in Urban Park Lácides Segovia

The research project developed in the Urban Park Lácides Segovia was in charge of the Biontessori Research Group, a research group comprised of students from the Montessori School of Cartagena led by professor Juan Felipe Restrepo Mesa. The environmental research projects developed by the Biontessori group are carried out within the framework of the PRAE (school environmental projects), which are national mandatory pedagogical projects that promote the analysis and understanding of local, regional, and national environmental problems and potentials, and generate spaces for participation to implement solutions by natural and socio-cultural dynamics (Colombia and MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE 2016). The projects are also associated with Colombian Ondas Program, of the Directorate of Vocations and Training in Science, Technology and Innovation, of the Deputy Minister of Talent and Social Appropriation, which seeks that children, adolescents and young become interested in research and development attitudes and skills to find in science and research a passion and a possible life project (Colombia and MINISTERIO DE AMBIENTE Y DESARROLLO SOSTENIBLE 2016). Biontessori performs research projects on several topics including citizen science, and the research performed in the Lacides Segovia is only one of them.

Primary data was collected via an interview with Professor Juan Felipe Restrepo Mesa, coordinator of the Biontessori Research Group. The main findings are described below.

Most of the projects involve data collection, for instance, they have created several inventories of fauna and flora of the ecosystems present in Cartagena, they have analyzed the changes in the distribution of native and exotic bird species, they have registered changes in abundance in certain species and have found impacts of land use change on biodiversity by analyzing satellite images. The projects carried out by the group have won several national and international awards. They are also active in international initiatives such as Global Big Day and collect information all around the year. The group has also collaborated with entities such as NASA and ESRI and contributed to NASA's GLOBE program, where they share the data from their research. Alongside birdwatching, the group has also collected information about the water quality of the cienagas in Cartagena and compared the parameters of the water quality with bird populations. With the support of ESRI, they have integrated GIS into their research, and they have collaborated with universities in Cartagena that have resulted in the publication of journal articles and support of dissertation projects.

In the Urban Lácides Segovia Park, they performed an inventory of the flora of the place and with the i-Tree tool, they calculated the ecosystem services that each tree provides and how much it costs to the city to lose those trees. Most of the research projects of the group are located in public places such as the park, the Cienaga de la Virgen, and the Juan Angola River but they also work in a private property owned by the school. The funding of the projects comes from different sources such as the school's funding, the award of the group, university collaborations, and the support of the families. They also receive non-monetary financing.

They also collaborated with the EPA and Cardique, they created QR codes for the Lacides Segovia Park with information from their bird inventories, they used information from Cardique's monitoring activities of the cienagas, and they also shared their results with them. The Research Group also involves the local communities, for instance on the Global Big Day they lead the bird identification process, show the main species that they can find, and teach people how to use the mobile applications.

The reach of the Biontessori Group has extended to other schools and communities outside Cartagena, they have led several training courses on the different tools they use, such as the Globe program and ArqGIS. The training is primarily conducted by Professor Juan Felipe. They also collaborate with local foundations and NGOs. For instance, they have supported the development of ecotourism projects in small communities near Cartagena.

Some pictures of the Urban Park Lácides Segovia are shown in Figure 13.

Figure 13. Pictures of the Urban Park Lácides Segovia. Source: Author.

5.7 Water as Leverage

Water as Leverage is an international cooperation program focused on water and climate adaptation in the city of Cartagena and its objective is to provide methodological tools and technical expertise for the formulation of sustainable infrastructure projects and resilient urban development (Water as Leverage 2023).

Primary data was collected via an interview with one of the project managers from the company Arcadis Netherlands, the leader of one of the teams that is participating in the project. The project has two multidisciplinary teams selected through an international public call for proposals, with the participation of Colombian, Dutch, and other companies and institutions. The main findings are described below.

The Water as Leverage project consists of the conceptual design of water-related nature-based solutions for Cartagena, which is the first of three steps for the development of the projects. Currently, they are waiting for the approval of the mayor's office for certain projects so they can define the next steps toward implementation. In total Water as Leverage presented 11 projects, for instance, one of them includes restoration and engineering solutions to the Juan Angola River, in Figure 14, we see the illustration included in the proposal shared by the interviewee.

Figure 14. Illustration of the project "socio-environmental border of the Juan Angola River". Source: Water as Leverage, 2024

The next steps for the project are unclear at the moment because Water as Leverage generally only contributes during the conceptual design, not the implementation, and because of the new government, the authority approves or denies the projects. The interviewee explained that Water as Leverage is considering participating in the next stages, alongside the other actors who are involved in the development of any environmental projects, this includes the environmental authorities (local and regional), private companies, public organizations, mayor's office, among others.

A relevant aspect of the project is the collaborative approach. They have implemented several spaces such as workshops and meetings with the communities and relevant stakeholders and they have considered their input about their territory's needs. The meetings have been reported as positive spaces for collaboration and have promoted enthusiasm in the community. The conceptual design stage is funded by the Dutch government, but the next steps need private and public funding, for that reason, they are contacting companies like banks that invest in environmental projects.

6. Discussion

In the previous sections of this document, we responded to the research questions presented in the introduction. **The first research question** (What are some of the key water-related challenges in Cartagena?) was answered in the results chapter by explaining what are the main social and environmental challenges that are being addressed by the eight projects and plans included in the interviews. **The second research question** (What are some prominent examples of water-related NBS?) was answered in the methods chapter with the list of the projects and plans that can be considered NBS and agreed to be included in the research and the results as well. **The third research question** (What do we know about their implementation strategies and effectiveness?) was also answered in the results chapter during the interviews where the professionals in charge of the projects explained the management strategies normally used by the identified actors in the city of Cartagena. In the current chapter, we will answer **the fourth research question** (What do these tell us about the role of NBS in addressing urban water challenges in the future?) by analyzing how the current projects integrate the variables explained in the literature review chapter and support or hinder the effectiveness of NBS design, implementation and monitoring.

Due to the current state of the NBS literature and limited monitoring and data on impacts clearly attributable to NBS, I can't produce an analysis stating that the projects and plans in Cartagena are effective and promoting urban resilience, but with the resources that have been identified and incorporated into this document, I will analyze which variables of Cartagena's NBS management could promote effective or ineffective NBS results. The discussion will consist of three sections, external factors and internal factors which constitute the current problems of Cartagena, and the management variables, which are the themes identified by the code and thematic analysis

explained in the methods chapter. The themes are aligned with the literature review variables but are not the same.

6.1 External factors

The external factors influencing the effectiveness of NBS are related to e.g. climate change, issues that have been identified by several actors such as National Parks and the local environmental authorities. According to Colombian National Natural Parks, Colombia is one of the most vulnerable countries to the effects of climate change (PNNC 2020) Because of its socio-economic conditions and geographic location in the tropics, where climate phenomena are less predictable than in other regions of the world (Richerzhagen et al. 2019). Also, Cartagena is especially vulnerable inside the Colombian context because is a coastal city, and coastal cities face different rates of risks, exposure, and sensitivity than other types of cities (Luna-Galván and Vargas-Chaves 2018; Uribe et al. 2022). "According to climate models, a 2 ◦C rise in temperature would lead to a further increase in sea level that would leave 25% of the population and residential properties in the city affected by flooding during high tides." (Richerzhagen et al. 2019, 7). Even though climate change issues were only mentioned by the Biontessori Research group interview, it is still a relevant topic in official documents such as the National Natural Parks and the city's Forestry plan.

6.2 Internal factors

According to the interviews, the main environmental problems in Cartagena include – among others - water pollution from several sources such as the port's activities, tourism, marine transportation, agricultural activities and poor water management by informal communities with no or inadequate infrastructure (e.g., illegal dumping in the cienagas), which are also a social

problem. These are common to many cities around the world, and include problems such as limited green space and vegetation cover, invasive species, deforestation, and loss of biodiversity. Similarly, the main social issues reported in the interviews are related mostly to vulnerable populations with inadequate access to basic services, such as illegal waste dumping in water bodies and other ecosystems, invasion of public land such as the 30-meter strip of land around water bodies, areas protected by law and that require relocation, poverty, inequality, racism, sexism, overpopulation, low education levels, and others. Another internal factor is the relationship between people and the authorities, in several projects there have been conflicts and activities have had to stop.

6.3 Management variables

6.3.1 Top-down governance

Most of the projects included in the research present a top-down governance arrangement. This is due to legal requirements and local initiatives. This means that the decisions are taken by government institutions, in Cartagena this would include the mayor's office, EPA Cartagena, and the national government, which includes the environmental ministry. According to the literature, this can promote NBS effectiveness or obstruct it (Martin et al. 2021; Midgley et al. 2021) Because the policy decisions are taken with only one set of perspectives (the authority perspective), which can limit the achievement of goals and the inclusion of the community priorities, but also could guarantee justice because public authorities have more accountability mechanisms for transparency (Martin et al. 2021). The findings suggest that in the case of Cartagena, the top-down governance arrangements have achieved both positive and negative impacts, but for future research in Cartagena, it would be worth including citizen-led NBS.

An important factor reported by the projects is the recognition of social vulnerabilities and their complex responses such as relocation of entire neighborhoods. This strengthens the effectiveness of NBS because it integrates the local context into the decision-making process (Dushkova and Haase 2023), and increases the probability of producing direct and indirect benefits to specific families and entire neighborhoods (Dorst et al. 2019; Sowińska-Świerkosz and García 2022). Nevertheless, this recognition seems appropriate on paper but in reality, when asked during the interviews if the projects have identified impacts on the neighborhoods, they explain some improvements but no physical transformation of streets and houses or relocation activities, so it is expected that these actions will take more time.

The capacity of actors is also relevant to discuss in the governance variable because it was found that public entities are understaffed, and professionals have several responsibilities that cause delays in everyday activities, and therefore the performance of plans and programs is being affected. This contextual precondition of having authorities with not enough team members affects NBS's effectiveness because it slows down the activities that are needed to achieve the goals of the NBS (Woroniecki et al. 2023), for instance, in the urban forestry plan the staff for the planting session is not been hired yet so planting the trees takes more time than anticipated or they have to request support from other entities. During my visit, they requested the support of high school students.

6.3.2 Collaboration

The participatory approaches implemented in most of the projects, in the form of workshops and governance tables, involve the community in several stages of the planning, implementation, and monitoring of NBS. This could be a positive indication that the NBS in Cartagena might be effective because from the literature we understand that citizen involvement and the consideration of local perception is key for NBS's production of benefits (Ferreira et al. 2020; Palomo et al. 2021; Woroniecki et al. 2023), but further research is needed to state that the collaboration strategies are satisfactory to the majority of the actors because this study only includes the perception of the decision makers. The different projects in Cartagena involve leaders, councils, and communal organizations that would be relevant to interview and understand their perspectives on the efforts implemented by the authorities.

Collaboration with different institutions from different scales and jurisdictions was also a common result for the plans and projects, for example with the collaborative arrangements between the EPA and Cardique for the monitoring of water bodies, but there was not enough information about how effective communication between actors is, especially because the challenges that the plan are trying to tackle involve large-scale activities. The collaboration between authorities with different scale jurisdictions is a good indicator of NBS effectiveness because it improves the coordination of activities and the general creation of local and regional impacts, and therefore the probability of changing an SES (Sekulova et al. 2021; Midgley et al. 2021).

The plans, programs, and projects also reported collaboration with other sectors such as private companies, like the company that provides public sanitation services (Pacaribe), foundations and

NGOs, and different departments of the mayor's office (i.e. infrastructure, and security departments). This is a positive input to NBS effectiveness because different sectors can receive support from each other in areas that are not their expertise, share responsibilities, and improve the chances of creating benefits (Dorst et al. 2019). Within the multisectoral collaboration, most of the plans and projects involve a mixture of NBS with green and grey infrastructure. This is evident for the Cienaga de la Virgen Plan and the Juan Angola River where they are integrating engineering interventions like water pumps, channels, and waste collection infrastructure. The combination of these strategies provides more benefits than only one type of intervention (Turner et al. 2022; Anderson et al. 2022).

We also found collaboration between different departments of the same institutions (e.g. EPA's biodiversity and education department for the Urban Forestry Plan), which is a complicated factor for NBS because it could be both positive or detrimental to NBS effectiveness (Ershad Sarabi et al. 2019). However, the interview and survey applied in this research did not focus on this type of collaboration, so the evidence is not sufficient to make a statement and analysis. Similarly, the projects and programs in Cartagena also have alliances with different projects and initiatives that have similar goals (Cienaga de la Virgen plan and Sustainable Neighborhoods program, and the Juan Angola River Plan and the land management plan of the city), this creates the possibility of promoting synergies between different efforts and achieving results more efficiently (Ferreira et al. 2020; Mell, Clement, and O'Sullivan 2023; Martin et al. 2021). Overall the collaborative approaches used by the projects and programs could lead to effective NBS design, planning, and implementation but more information is needed, particularly because most of the problems of Cartagena involve the entire city, making collaborative new approaches more challenging.

6.3.3 Funding

The financial arrangements found for the plans, programs, and projects that involve NBS in Cartagena are mostly public or mixed private/public. According to the literature, public-funded NBS tend to be short-term, which applies to the cases in Cartagena because of their temporary hold due to the new government. This short-term funding is related to inefficient NBS and the need to request different sources of funding (Ershad Sarabi et al. 2019). It was also common to find plans and projects with limited funding, a situation that is well-registered for developing countries alongside weak government institutions (Richerzhagen et al. 2019; Abunyewah et al. 2023), this condition is important to consider the effectiveness of NBS in developing countries in the future.

6.3.4 Political continuity

Every project, plan, and program included in this research mentioned the difficulties of dealing with the 4-year cycles of the new government because it causes a temporary hold on every environmental intervention until the projects are again approved and new funding is assigned. This is a well-documented barrier to NBS effectiveness because the transformation of SES is caused by long-term planning and efforts (Beumer and Martens 2013; Mell, Clement, and O'Sullivan 2023; Ershad Sarabi et al. 2019). This situation also causes the projects and plans to stay in the early stages for a long time, and the planning excludes long-term timelines and significant changes in the roles of the actors.

The lack of political continuity could provide spaces for activities related to the strategic management cycle because, during the pauses between governments, the former or future decision-

makers could perform a reevaluation of the effectiveness of the strategies involved in plans and programs (Lucas 2010) And start again if necessary or maintain the course of action.

6.3.5 Monitoring

The monitoring results for the projects, plans and programs covered by the research are varied. On the one hand, we have extensive monitoring of water quality, but poor monitoring of the impacts on former environmental projects such as ecological restoration and conservation. A straightforward result from the studied cases is that NBS in Cartagena have no clearly documented results attributed to NBS, both flooding and pollution problems persist. Overall, water-related NBS have work to not only to actually improve the conditions of the rivers and cienagas of Cartagena, but also measure impacts, because without monitoring the city does not have evidence of the achievement or failure of the project's goals (Chrysoulakis et al. 2021), and because the problems affecting this ecosystem are complex and multidimensional.

A finding that has the potential to promote the effectiveness of NBS is the promotion of articulated monitoring, as proposed by the Master Plan for the Ecological Restoration of the Bay of Cartagena. These monitoring strategies are supposed to implement collaboration between institutions, long-term measurements, and reporting methods for sharing the results. If this monitoring is achieved the relationship between actors might improve and the decision-makers would have updated information about the state of Cartagena's condition, an essential factor for effective NBS (Ershad Sarabi et al. 2019; Palomo et al. 2021).

6.3.6 Communication

The communication strategies for the plans and projects are also varied. None of the projects report up-to-date information to the public except the Biontessori Research Group, but the decision makers produce the information and share it internally with relevant stakeholders. This communication is a positive factor that could promote NBS effectiveness because if the stakeholders are informed, the perceived effectiveness and general acceptance of NBS, from the local community increases (Dushkova and Haase 2023; Martin et al. 2021; Mahmoud et al. 2021).

6.3.7 Education and capacity building

From the results we can state that all the projects included in the research involve different types of education, from initiatives with local schools, training to specific skills, to entrepreneurial efforts, which are directly related to capacity building because families get new sources of income such as the recycling organizations from Cienaga de la Virgen and mangrove nurseries and sustainable use efforts for fishing practices. These education efforts are a variable that improves NBS effectiveness because they enhance the socio-economic levels of the community and the support from the community to the projects (Martin et al. 2021; Ershad Sarabi et al. 2019).

It is also relevant to highlight the work done by The Biontessori Research group, from the Montessori school because they regularly monitor and report relevant information about the current state of Cartagena's biodiversity, they include the community in their citizen science work, they collaborate with local authorities, universities, and other institutions, and generate positive impacts on the life of students who obtain a better understating of their context and then become informed adults that can transform their SES. Also, by their performance in national and

international competitions, they bring attention to Colombian issues opening new opportunities not only for their school and students but for the entire environmental sector. These multidimensional benefits improve the effectiveness of NBS and citizen science efforts should be considered more in studies such as this one (Restemeyer and Boogaard 2021; Calderón Cendejas et al. 2021).

Additionally, a result of the projects and programs in Cartagena was an increase in environmental stewardship. Every interview mentioned how the NBS initiatives have increased the environmental awareness of different communities and how their roles have shifted from passive actors to active actors that request changes to the government and the authorities and take charge of their territory's transformation. The fact that entire neighborhoods are aware of their connections and dependency on the state of the ecosystem is an indication of the effectiveness of NBS, considering that the strengthening of the relationship between people and their environment and empowering historically marginalized communities is a well-known effect of NBS (Turner et al. 2022; Dunlop et al. 2024).

6.3.8 Water focus

The projects, plans, and programs included in this research have a strong water focus and their impacts are coherent with the information reported by Oral (2020). The ecological restoration efforts in the project of La Cienaga de la Virgen, the Juan Angola River, the Bay of Cartagena, and the National Natural Park are targeting water pollution, wastewater control, waste management, retention of rainwater, and the creation of green spaces that could promote a transformation in the city. But as has been mentioned before, since the projects do not have

extensive monitoring of the different dimensions of the city and neighborhood it is not possible to say that all the water challenges of Cartagena are being currently addressed by effective NBS.

7. Conclusions and recommendations

Cities around the world face a complex web of unsustainability challenges that can be potentially addressed by initiatives such as NBS, as discussed in the case of Cartagena, Colombia in this thesis. The research studied and answered four research questions about how Cartagena transforms or not its relevant water problems via NBS. The NBS literature highlights some of the mechanisms via which society can positively influence their environment. Although the impacts of these mechanisms are not easy to measure and directly attribute to NBS, we know enough about the factors that influence NBS effectiveness that can serve as direct or proxy indicators of NBS performance. The research questions have been answered in the broader context of how Cartagena creates and maintains conditions that influence the city's environment specifically water-related risks and vulnerabilities and its resilience. The main sources of primary data were interviews with relevant actors associated with carefully selected, water-related NBS, involved in the decisions that impact not only the immediate environment of the NBS but often larger areas or the entire city. The study of the selected NBS in Cartagena presents diverse results, focused on conditions that are known from the literature to affect NBS performance. These include, for example, collaboration with local communities, different sectors, and different authorities at different scales. Collaborative mechanisms across multiple stakeholders and levels of governance related to NBS and water indicate that some of the conditions for increased resilience to environmental and anthropogenic change are in place, but it also presents conditions that are commonly found in developing countries, such as vulnerable social institutions that need improvements such as increasing employment related to NBS and long-term planning that hinder the effectiveness of NBS and reduce the city's resilience.

The implications of answering these research questions and obtaining these results are that NBS which have multiple impacts and often involve collaborative management arrangements need to be integrated into structural transformation strategies to achieve the goals they set out to achieve. Cartagena's authorities are implementing several actions, but they still face barriers that will delay the timelines or stop the activities completely, and they still face uncertainty and problems out of scope, especially because the issues are all connected. Cartagena possesses a network of water bodies, and this reflects on the environmental and social issues. What happens in the Cienega will affect the rivers and what occurs in the rivers will affect the bay and the coral reefs. So new decision-makers need to embrace integrated perspectives and initiate and be involved in self-reflecting exercises about how past and present initiatives worked, and what and how can be improved.

The main limitations of this research are related to data. The NBS that were included had a public focus, because my network leans towards the Colombian public sector, but the results might have been different if I had interviewed companies like Ecopetrol and Argos, big companies with big impacts in the city that are probably involved in several environmental projects because of their mitigation strategies. Also, in the absence of time and security restrictions, I could include the perspective of more actors involved in the NBS, for instance, local leaders, environmental defenders, local schools, and universities. Future research should include more diversity, more perspectives, and more time.

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9. Annexes

I. Interview protocol and survey in Spanish

Protocolo de entrevista

Introducción

Gracias por tu tiempo y por aceptar participar en esta entrevista. Soy estudiante del programa de Maestría en Ciencias y Políticas Ambientales en la Universidad Europea Central en Viena, Austria,

y actualmente estoy escribiendo mi tesis sobre Soluciones Basadas en la Naturaleza relacionadas con el agua y su implementación en Cartagena.

Descripción del Proyecto de Investigación

Mi tesis tiene como objetivo comprender cómo se está implementando las SBN en Cartagena, quiénes están involucrados en el desarrollo de este tipo de proyecto, qué roles están incluidos, cuáles son los objetivos, quién se beneficia de las SBN y si hay algún impacto hasta ahora. En general**, quiero averiguar si influyen en la resiliencia de la ciudad**.

Explicación del Proceso de Entrevista

Nuestra entrevista tomará entre 30 minutos y una hora. ¿Estás de acuerdo con esto?

Algunos detalles sobre el proceso de entrevista: esta es una entrevista de investigación cualitativa y no es como una encuesta o cuestionario. Me interesa conocer las dinámicas de implementar un proyecto como una SBN en esta ciudad y me gustaría entender el trabajo detrás de estas iniciativas. Cuanto más específico seas sobre los procesos de las SBN, más podré entender el papel de los proyectos y su impacto en el medio ambiente y la calidad de vida de las personas.

Si en algún momento deseas terminar la entrevista, puedes hacérmelo saber.

Explicación del Uso de los Datos de la Entrevista y Acuerdo sobre el Anonimato

Esta investigación es parte de mi tesis, un requisito obligatorio para obtener mi título de maestría. La entrevista será transcrita y analizada por mí. La transcripción no se incluirá en la tesis, pero podría ser solicitada por mis profesores en cualquier momento. ¿Tienes alguna objeción a que te entreviste y use tu nombre en este proceso?

La entrevista se almacenará en la cuenta de OneDrive proporcionada por mi universidad, a la que solo yo tengo acceso.

Tendríamos que grabar la entrevista para poder tener una entrevista más libre; luego simplemente puedo transcribirla. ¿Está bien si grabamos esta entrevista?

En cualquier momento durante la entrevista, puedes decidir finalizar la entrevista por cualquier motivo y, hasta 3 días después de la entrevista, puedes solicitar que los datos de la entrevista no se incluyan en el estudio y que tus datos sean eliminados.

"¿Tienes alguna pregunta sobre el proyecto de investigación o el proceso de entrevista?"

Preguntas de la Entrevista.

I. Información sobre la persona

Su nombre, profesión, organización, tiempo en el cargo.

¿Cuánto tiempo has estado involucrado en las SBN?

II. Información sobre las SBN

¿En qué año comenzaron?

¿Cuál es la etapa actual de las SBN?

¿Cuál es la ubicación exacta de las SBN?

¿Sabes que extensión tiene?

¿Cómo se toman las decisiones sobre el proyecto? ¿Cuántas personas/empresas/instituciones?

¿ustedes colaboran con otros proyectos?

- Son útiles? De que manera?
- ¿Sabes si hay otros proyectos como este? ¿Con los mismos objetivos?
- Sabes si el NBS ayuda a otros NBS? A las metas de otro NBS?

¿Crees que sea necesario que el proyecto interactúe con otros proyectos similares?

III. Planificación de las SBN

¿Cómo se iniciaron las SBN? ¿fue obligatorio a algo?

¿Cuáles fueron los motores del proyecto? ¿Se tenía algún problema claro durante la planeación, para resolver? que tipo de datos había antes?

¿Quién fue el principal promotor?

¿Cuántas personas estuvieron involucradas?

¿Cuántas organizaciones estuvieron involucradas en la planeación? ¿algo de investigación?

¿Quién fue el público objetivo durante la planeación?

¿conoces que actividades principales se llevaron a cabo durante la planificación?

¿Hubo participación civil? ¿Consulta, grupos? ¿Cómo?

¿Cuál es la fuente financiera? ¿Qué tan detallado es el esquema financiero?

¿Cuánto costo el proyecto?

¿Hay inversiones no monetarias?

¿Está conectado con el POT de la ciudad? O otra figura de ordenamiento? Regional? Pomca?

¿Cuántas metas y objetivos se establecieron? En que temas?

¿Hubo objetivos específicos a largo plazo?

¿Cuáles son las herramientas legales que utilizan? Aspectos legales

IV. Implementación de las SBN

¿Cuánto tiempo llevó implementar las SBN? Desde la planeación

¿El terreno en donde se desarrolló el proyecto de quién es?

¿Cuántas empresas estuvieron involucradas en la implementación?

Como describirías la participación ¿Hubo apoyo civil? ¿Cuál fue la actitud general de los vecinos?

¿Continuó el proyecto el trabajo participativo si lo había en la planificación? ¿Hay reuniones o talleres?

¿Cuales fueron las actividades principales durante la implementación?

¿Alguna vez hubo conflictos? ¿Sobre las metas?

¿cree que las personas involucradas en la SBN son conscientes de los problemas ambientales que intenta resolver?

V. Monitoreo de las SBN

¿Existe un sistema de monitoreo?

¿Quién recibe la información? ¿Y quién puede acceder a ella? ¿En qué forma? Que pasa con ella

¿Hay algún tipo de monitoreo civil?

¿hay algúna ejemplo de datos que hayas cambiado a lo largo del desarrollo del proyecto? Por ejemplo que información obtenida a través de monitoreo haya cambiado las estrateigas del proyecto?

¿Considera que los datos que tienen actualmente son suficientes? ¿Que cambiarían? ¿Que incluirían?

VI. Resultados de las SBN

¿Sabes si las SBN ya tienen resultados? ¿Se han encontrado impactos? ¿evidencia?

¿indicadores importantes?

¿Han cambiado el barrio, los alrededores, los precios de las casas?

¿Cuáles considera que son los principales beneficios del proyecto?

¿Quién recibe estos beneficios? Si los hay

I. Otros

¿Qué es lo que más ayudo al éxito del proyecto? En su opinión

¿consideras que tiene algo de innovador?

Apoyo de actores políticos antes

Colaborativo, diferentes puntos de vista

II. Interview protocol and survey in English

Interview Protocol

Introduction

Thank you for your time and for agreeing to participate in this interview. I am a student in the Master's program in Environmental Science and Policy at the Central European University in Vienna, Austria, and I am currently writing my thesis on Nature-Based Solutions related to water and their implementation in Cartagena.

Description of the Research Project

My thesis aims to understand how Nature-Based Solutions (NBS) are being implemented in Cartagena, who is involved in the development of such projects, what roles are included, what the objectives are, who benefits from the NBS, and if there has been any impact so far. In general, I want to find out if they influence the resilience of the city.

Explanation of the Interview Process

Our interview will take between 30 minutes and one hour. Do you agree with this?

Some details about the interview process: this is a qualitative research interview and is not like a survey or questionnaire. I am interested in understanding the dynamics of implementing a project like an NBS in this city and would like to understand the work behind these initiatives. The more specific you are about the NBS processes, the better I can understand the role of the projects and their impact on the environment and the quality of life of the people.

If at any point you wish to end the interview, please let me know.

Explanation of the Use of Interview Data and Agreement on Anonymity

This research is part of my thesis, a mandatory requirement to obtain my master's degree. The interview will be transcribed and analyzed by me. The transcription will not be included in the thesis but may be requested by my professors at any time. Do you have any objections to me

interviewing you and using your name in this process? The interview will be stored in the OneDrive account provided by my university, to which only I have access. We would need to record the interview to be able to have a freer conversation; then I can simply transcribe it. Is it okay if we record this interview? At any time during the interview, you can decide to end the interview for any reason and, up to 3 days after the interview, you can request that the interview data not be included in the study and that your data be deleted. "Do you have any questions about the research project or the interview process?"

Interview Questions

I. Information about the Person

Your name, profession, organization, time in the position.

How long have you been involved in NBS?

II. Information about the NBS

In what year did they start?

What is the current stage of the NBS?

What is the exact location of the NBS?

Do you know the extent of it?

How are decisions made about the project? How many people/companies/institutions?

Do you collaborate with other projects?

Are they useful? In what way?

Do you know if there are other projects like this? With the same objectives?

Do you know if the NBS helps other NBS? The goals of another NBS?

Do you think it is necessary for the project to interact with other similar projects?

III. Planning of the NBS

How were the NBS initiated? Was it mandatory for something?

What were the drivers of the project? Was there a clear problem during the planning that needed to be solved? What kind of data was available before?

Who was the main promoter?

How many people were involved?

How many organizations were involved in the planning? Any research?

Who was the target audience during the planning?

Do you know what main activities were carried out during the planning?

Was there civil participation? Consultation, groups? How?

What is the financial source? How detailed is the financial scheme?

How much did the project cost?

Are there non-monetary investments?

Is it connected with the city's Land Use Plan (POT)? Or another planning figure? Regional? Pomca?

How many goals and objectives were set? On what topics?

Were there specific long-term objectives?

What are the legal tools they use? Legal aspects.

IV. Implementation of the NBS

How long did it take to implement the NBS? From planning.

Whose land was the project developed on?

How many companies were involved in the implementation?

How would you describe the participation? Was there civil support? What was the general attitude of the neighbors?

Did the project continue participatory work if it existed in the planning? Are there meetings or workshops?

What were the main activities during implementation?

Were there ever any conflicts? About the goals?

Do you think the people involved in the NBS are aware of the environmental problems it tries to solve?

V. Monitoring of the NBS

Is there a monitoring system?

Who receives the information? And who can access it? In what form? What happens to it?

Is there any kind of civil monitoring?

Is there an example of data that has changed throughout the project development? For example, information obtained through monitoring that has changed the project strategies?

Do you consider that the data you currently have is sufficient? What would you change? What would you include?

VI. Results of the NBS

Do you know if the NBS already has results? Have impacts been found? Evidence?

Important indicators?

Have the neighborhood, surroundings, house prices changed?

What do you consider the main benefits of the project?

Who receives these benefits? If any.

Others

What has helped the project succeed the most, in your opinion?

Do you consider it innovative in any way?

Support from political actors before.

Collaborative, different points of view.