Evaluating Nature-Based Solutions through the Lens of Nature's Contributions to People in Urban Areas

Master Thesis

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Abstract

Urban areas face increasing pressure from climate change, pollution, biodiversity loss, and rapid urbanization. In response, nature-based solutions (NbS) have gained attention for their potential to address these complex challenges while enhancing urban resilience and sustainability. However, the evaluation of NbS benefits has largely relied on the ecosystem services (ES) framework, which tends to overlook relational, cultural, and context-specific values. These gaps can limit the effectiveness and fairness of NbS, especially in diverse urban contexts. To address this gap, this thesis explores whether the nature's contributions to people (NCP) framework can offer a more inclusive approach to evaluating the benefits of NbS in urban areas.

The main research question guiding this thesis is: *"How can the Nature's Contributions to People framework be applied to evaluate the benefits of nature-based solutions in urban environments?"* To answer this, the thesis follows four steps. First, it compares existing evaluation frameworks, highlighting limitations of the ES approach and how they can undermine just NbS implementation. Second, it narrows down NCP categories most relevant to urban environments, confirming the relevance of NCP for cities. It then analyses how urban NbS contribute to those categories, which formed a basis for selecting a promising NCP category for further spatial analysis. Third, it compiles suitable indicators for each NCP category. Lastly, to validate the approach, a focused selection of NCP 16 indicators was tested through a spatial analysis using ArcGIS, applied to the case study of park Frankendael in Amsterdam.

The analysis demonstrates that the NCP framework adds value by not only capturing biophysical and economic benefits but also revealing who receives these benefits, who is excluded, and how access is distributed. These insights support more inclusive and equitable urban NbS evaluation. While this study focused on one NCP category, it provides a replicable methodology for broader applications. Future research should expand indicator testing across additional NCP categories, urban context, and NbS types to further strengthen inclusive NbS evaluations.

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1. Introduction

Currently, more than half of the global population resides in cities, a figure expected to rise to two-thirds by 2050 (Grimm et al., 2023). Cities are key contributors to climate change. Currently, cities are responsible for producing 50% of global waste, approximately 70% of greenhouse gas emissions, and 75% of energy and natural resource consumption (Bona et al., 2022). This increases pressure on rural areas and natural ecosystems to supply water, energy, food, and to handle waste (Bona et al., 2022).

Cities are contributors to climate change, and they are also affected by it. The rising global temperatures lead to rising sea levels, increased occurrences of extreme weather events like floods, droughts, heatwaves, and storms, and an increased spread of tropical diseases. This has costly consequences on cities, affecting their basic services, infrastructure, housing, livelihoods, and public health (UNEP, n.d.). Simultaneously, cities face challenges such as population growth, mass urbanization, and expansion of urban development (Twohig et al., 2022). Therefore, sustainability holds significant relevance as urban environments face impacts from climate change.

The need for urban resilience is prevalent to deal with these impacts. Urban resilience involves an urban system that thrives during periods of stability and adapts, reorganizes, and grows during times of change or disruption (Bush & Doyon, 2019). A way to enhance urban resilience and climate adaptation is through nature-based solutions (NbS).

1.1. Nature-based solutions

NbS are, as the term states in itself, solutions that are inspired and supported by nature to address societal challenges (Raymond et al., 2017). The European Commission (2023) defines NbS as “solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience” and they bring more diverse nature and processes into cities, through locally adapted, resource-efficient and systematic interventions. As a result, NbS can help contribute to global goals such as the CBD Global Biodiversity framework for 2021-2030, the implementation of the Paris Agreement, the EU Biodiversity Strategy, Land Degradation Neutrality Targets, and multiple UN Sustainable Development Goals (PBL, 2020-2022).

There are multiple advantages to NbS, such as environmental, social, and economic benefits. The environmental benefits include thermal comfort and carbon sequestration, air pollution filtering, water retention, flood protection, biodiversity enhancement, and ecosystem restoration (Faivre et al., 2017; Grimm et al., 2023; Kandel & Frantzeskaki, 2024). Not only can they mitigate the impact of climate change, but also provide social benefits by providing cultural ecosystem services, like recreational spaces and experiencing nature, social interaction, and building community cohesion, which contributes to human physical and mental health and well-being (Bush & Doyon, 2019; Grimm et al., 2023; Kandel & Frantzeskaki, 2024). When comparing NbS to traditional grey infrastructure (focuses on only one function per infrastructure) that is often associated with high cost, inflexibility, and conflicting interest, NbS are potentially more cost-effective, more flexible in accepting changes to system design and management, and adapt better to shifting risk profiles or environmental changes, developing insurance value of ecosystems (Faivre et al., 2017), increase the sustainable use of resources and energy (Faivre et al., 2017), and are more resilient (Bush & Doyon, 2019; Grimm et al., 2023).

1.2. The need for better evaluation

Despite these advantages, there are also disadvantages to NbS. Although NbS are multifunctional, they can't solve every problem and there are trade-offs between different types of NbS in terms of ecosystem services and inconvenience they produce. An example of inconvenience is that new NbS projects in urban areas can increase land prices and rent. By making neighborhoods more attractive, the NbS may unintentionally contribute to gentrification and the displacement of the very communities they aim to support. These inconveniences can be exacerbated by ignoring the connections between NbS and the social and technological aspects of cities (Grimm et al., 2023). Another problem that arises is sustaining co-production. It is difficult to maintain continuous collaborative processes involving diverse groups for lasting stewardship and scaling of NbS, and if it's not implemented correctly, it risks reinforcing participation fatigue, limited representation, and power imbalances (Hölscher et al., 2024). Furthermore, there are challenges with scaling NbS to levels comparable to traditional grey infrastructure, their substitutability or hybridizing with built infrastructure, and their integration into rapidly developing urban areas (Grimm et al., 2023). These disadvantages show that the implementation of NbS is complex, given the multiple ecosystem services, their multi-functionality, and trade-offs (Bush & Doyon, 2019).

It is important that NbS are implemented and assessed in a just way when working with diverse urban settings, as the trade-offs can create winners and losers (e.g., displacement of vulnerable communities). There is a need to develop practical and targeted guidance for the assessment and balancing of multiple benefits of NbS and creating frameworks to facilitate the mainstreaming of NbS in urban planning (Wickenberg et al., 2021).

Currently, most mainstream evaluation frameworks of NbS rely on the ecosystem services (ES) framework. This framework has been great for the inventory of the benefits of NbS through biophysical and economic value. However, they lack in accounting for these disadvantages described, especially for relational, cultural, and context-specific values.

To address this gap, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) introduced the Nature's Contributions to People (NCP) framework, which builds upon the ES concept (Díaz et al., 2018). This is a promising framework for evaluating the benefits of NbS as it tries to be more holistic and inclusive. This is important for NbS in urban environments, because cities deal with many different stakeholders and people with different ways of thinking and cultures.

This leads to the central objective of this thesis: to evaluate NbS in urban areas through a NCP lens, by applying a spatial analysis to park Frankendael as a case study. This is relevant because NbS in urban settings have not been extensively studied using the NCP framework. This offers support for decision-makers, urban planners, and policymakers to make informed decisions regarding the evaluation of NbS in urban environments.

1.3. Research questions

This raises the following main research question: *"How can the Nature's Contributions to People framework be applied to evaluate the benefits of nature-based solutions in urban environments?"*

To answer this main research question the following four sub-questions were formulated:

- SQ1: What existing frameworks are used to evaluate the benefits of NbS and how does the most prominent one compare with NCP?
- SQ2: Which NCP categories are most relevant to urban environments, and how do NbS contribute to these categories?
- SQ3: What indicators or proxies can be used to assess NCP in urban NbS?
- SQ4: How can the NCP framework be applied to a case study of an urban NbS and what insights does this provide?

Figure 1 shows the broad research approach that was followed based on the research questions.

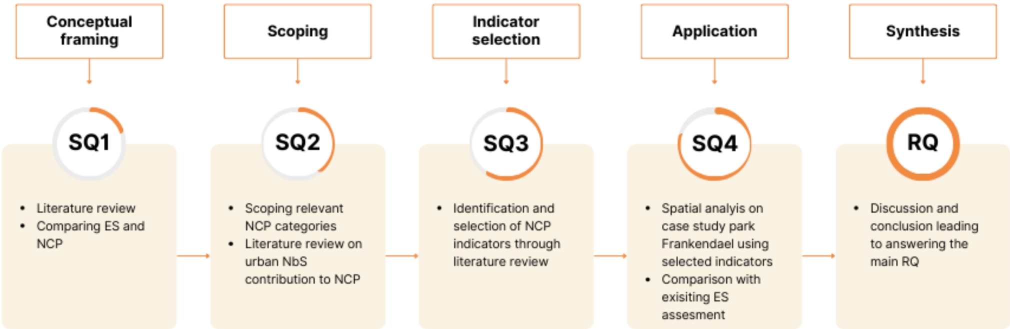

Figure 1: Research question flow diagram

This thesis is structured as follows. Chapter 2 contains the literature review leading to the knowledge gap. Chapter 3 describes the methods used to get the results presented in Chapter 4. Chapter 5 provides the discussion. Lastly, Chapter 6 presents the conclusion by addressing the main research question and its sub-questions.

2. Literature review

This section will answer SQ1: *"What existing frameworks are used to evaluate the benefits of NbS and how does the most prominent one compare with NCP?"* through a literature review. It begins by describing the methodology used for the literature review. It then provides an overview of existing frameworks used to evaluate the benefits of NbS. One prominent framework is selected for comparison with the NCP framework to explore its potential added value. The section concludes by outlining the knowledge gap that this thesis aims to address.

2.1. Literature methodology

The literature review was conducted by using databases such as Scopus and Google Scholar and research techniques like snowballing. The review aims to (1) explore existing frameworks for evaluating NbS benefits, (2) investigate limitations associated with the most used evaluation framework, and (3) compare it with the promising NCP framework. A range of search strings was used to ensure comprehensive coverage of relevant literature, including the following combinations:

- "NbS" OR "nature" AND "based" AND "solution*" AND "benefit*" OR "advantage*"
- "NbS" OR "nature" AND "based" AND "solution*" AND "limitation*" OR "disadvantage*" OR "disservice*"
- "nature-based solutions" AND "evaluation method*" OR "assessment framework" OR "benefit assessment"
- "evaluating" AND "framework" AND "urban" AND "nbs" OR "nature" AND "based" AND "solution*"
- "Impact assessment" AND "NbS" AND "urban"
- "ecosystem services" AND "limitations"
- "ecosystem services" AND "nature-based solutions" AND "urban" AND limitations

After screening article titles, approximately 90 studies were reviewed at the abstract level. Literature was evaluated for its relevance to NbS, urban contexts, ES, NCP and methodological clarity. Key review and conceptual papers (e.g., Díaz et al., 2018; Kadykalo et al., 2019) were prioritized for their foundational insights. Based on this process, 48 papers were selected for a full review.

2.2. Existing frameworks that evaluate NbS benefits

This section reviews existing frameworks that evaluate NbS in urban environments found in both academic literature and policy contexts. These frameworks include: co-benefits framework, multi-criteria decision making (MCDA), Resilience assessment framework (RAF), indicator-based frameworks, and ecosystem services (ES) frameworks.

The co-benefits assessment framework developed by Raymond et al. (2017) is one of the most cited holistic approaches. It provides a seven-stage process to identify, implement, and evaluate NbS across multiple societal challenges. It encourages stakeholder participation and includes multiple methods of evaluation, such as quantitative ecosystem service modelling (e.g., i-Tree), multi-criteria analysis, cost-effectiveness assessment, and participatory techniques like Q-method and fuzzy cognitive mapping. The framework is a valuable tool for guiding thinking and identifying the values of NbS implementations (Raymond et al., 2017). While this framework gives a good overview of all the steps necessary for NbS implementation, its evaluation section also includes indicators and ES-based approaches.

Croeser et al. (2021) and Wójcik-Madej et al. (2024) developed MCDA frameworks that are best suited to prioritize or select NbS options by evaluating multiple benefits simultaneously. Camacho-Caballero et al. (2024) linked MCDA to urban vulnerabilities to assess the extent to which NbS alter those.

RAFs such as those proposed by Beceiro et al. (2020), focus specifically on evaluating how NbS contribute to urban resilience in the context of stormwater management and control. While they offer a clear logic for linking NbS to resilience outcomes, their focus is narrower than general benefit frameworks.

Other frameworks focus more on indicators and metrics to evaluate NbS, such as Francés et al. (2021) and Jose et al. (2025) focus on developing performance metrics for assessing NbS outcomes. These include environmental, social, and economic indicators, often tailored to specific urban projects. While flexible and measurable, these approaches still typically draw from ES paradigms and may not fully capture lived experiences or diverse worldviews.

Lastly, several ecosystem services (ES) frameworks have been widely used to assess NbS benefits. Ecosystem service frameworks such as The Millennium Ecosystem Assessment (MA) (MA, 2005), The Economics of Ecosystems and Biodiversity (TEEB) (Maund et al., 2020), Common International Classification of Ecosystem Services (CICES) (Maund et al., 2020), and the Mapping and Assessment of Ecosystems and their Services (MAES) (Maes et al., 2015) provide classification systems for identifying and valuing ecosystem functions and services. While these have become foundational in NbS evaluations, they have been criticized for their emphasis on biophysical and economic metrics, and their limited ability to account for cultural, relational, and context-specific values (Kadykalo et al., 2019; Pascual et al., 2017).

Several frameworks were identified that offer valuable approaches for evaluating NbS in urban environments. However, the majority are either grounded in or contain elements of the ES concept. Among these, the MA framework stands out as the most foundational and influential. Therefore, this thesis adopts the ES framework as the most prominent existing evaluation framework. The ES framework described by the MA will be used to compare with the NCP framework, in order to explore the potential added value of the latter.

2.3. Ecosystem services

2.3.1. What are ecosystem services?

Throughout history, the relationship between people and nature has been understood in various ways. More recently, the concept of ES has permeated scientific research, government policies, multi-national environmental agreements, and science-policy interfaces (Kadykalo et al., 2019). The ES concept was formalized by the Millennium Ecosystem Assessment (MA). They defined ecosystem services as the benefits obtained from ecosystems and described them as provisioning (products obtained from ecosystems), regulating (benefits people obtain from regulation of ecosystem processes), supporting (services necessary for the production of all other ES), and cultural services (non-material benefits obtained from ecosystems) (MA, 2005). The MA relates these ecosystem services to human well-being as shown in Figure 2 (MA, 2005).

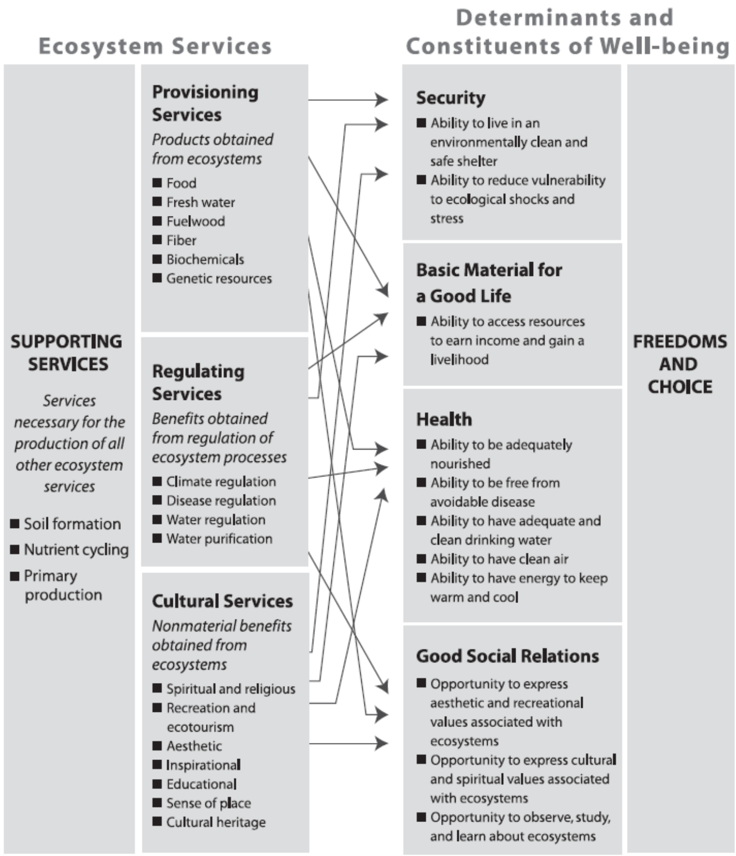

Figure 2: Ecosystem services described by the MA (2005)

The MA highlights economic valuation as an essential tool for decision-making in ecosystem management. While some impacts on human well-being can be assessed using specific indicators (e.g., human health), the MA acknowledges that such unidimensional measures are often insufficient. In cases where multiple impacts exist, economic valuation becomes particularly important, as it enables the comparison and aggregation of different ecosystem service benefits, reinforcing its role as a key assessment method (MA, 2005).

2.3.2. Limitations of ecosystem services

The ES framework has become a widely used tool to link ecosystems to human well-being and inform NbS in urban planning. However, several studies have highlighted critical limitations that challenge its effectiveness.

One of the cited issues is the overemphasis on economic and biophysical values, which tends to marginalize non-material and culturally embedded aspects of human-nature relationships (Hauck et al., 2012; Small et al., 2017; Díaz et al., 2018; Gómez-Baggethun & Barton, 2012; Kadykalo et al., 2019). While instrumental and sometimes intrinsic values are accounted for, relational values such as spiritual connection, identity, care, or ethical responsibility are largely excluded from ES assessments (Pascual et al., 2017; Kadykalo et al., 2019). Cultural ecosystem services are treated as a residual or standalone category and remain difficult to define, quantify, and integrate into policy frameworks (Small et al., 2017; Díaz et al., 2018). This has led to the frequent underrepresentation of values that are central to well-being but not marketable, such as aesthetic appreciation, emotional significance, and symbolic meanings (Small et al., 2017; Gómez-Baggethun & Barton, 2012).

A related concern is the semantic ambiguity and inconsistency in the use of key terms like ‘value’, ‘benefit’, or ‘use’. These are often interpreted through a monetary lens, which can confuse or exclude stakeholders who assign non-economic meanings to nature (Small et al., 2017; Kadykalo et al., 2019; Luederitz et al., 2015). This not only creates communication barriers between disciplines and policy arenas but also contributes to a materialistic framing of nature that may fail to capture the drivers of cultural and behavioral change (Small et al., 2017; Pascual et al., 2017).

Several scholars also emphasize the limited integration of local, indigenous, and plural knowledge systems in ES assessments, which often adopt a Western-scientific, expert-driven worldview (Díaz et al., 2018; Kadykalo et al., 2019; Pascual et al., 2017). As a result, many ES studies overlook community-based understandings of nature or fail to reflect the values of those most directly affected by NbS interventions (Luederitz et al., 2015; Raymond et al., 2017).

From a methodological perspective, ES research often relies on standardized indicators or single metrics, which simplifies complex, multifunctional outcomes of NbS. This is especially problematic in urban contexts, where NbS simultaneously deliver environmental and social benefits (Raymond et al., 2017; Costanza et al., 2017). Moreover, existing frameworks struggle to address trade-offs and synergies between services, particularly when these are unintended or occur across different spatial and temporal scales (Hauck et al., 2012; Costanza et al., 2017).

Additional institutional and operational challenges further limit the uptake of ES in practice. These include inconsistent valuation methods, high implementation costs, and weak institutional support (Costanza et al., 2017). In urban ES research, issues such as vague system boundaries, poor transferability between cities or regions, and insufficient contextual detail (including socio-political and ecological conditions) limit the utility of ES for urban governance (Luederitz et al., 2015). There is also a concern around the lack of stakeholder participation (Luederitz et al., 2015; Hauck et al., 2012). Without participatory engagement, the ES framework risks becoming a technocratic tool, detached from the real needs and values of urban residents (Small et al., 2017; Kadykalo et al., 2019).

To summarize, the ES limitations include a focus on economic and biophysical values, limited inclusion of cultural and relational aspects, and insufficient integration of local knowledge. As a result, it often fails to fully capture the diverse, context-specific benefits of NbS in urban settings.

2.4. Nature’s contributions to people

In 2017, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) introduced a new concept, Nature’s Contributions to People (NCP) (Kadykalo et al., 2019). This framework builds upon the ecosystem service concept popularized by the MA (Díaz et al., 2018). NCP are defined as ‘all the contributions, both positive and negative, of living nature (diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to people’s quality of life’ (Díaz et al., 2018). The NCP framework is described through two perspectives: a generalizing perspective and a context-specific perspective.

2.4.1. Generalizing perspective

The generalizing perspective is analytical in purpose; it aims to find a universally applicable set of categories of flows from nature to people. This perspective categorizes nature’s contributions into three overlapping groups: material, non-material, and regulating contributions (see Figure 3) (Díaz et al., 2018).

- Material contributions include substances, objects, or other material elements from nature that directly support people's physical existence and material assets. They are often physically consumed, such as food, water, energy, and materials.
- Non-material contributions highlight how nature influences the subjective, psychological dimensions of human life, both personally and collectively. Examples are forests providing opportunities for recreation and inspiration, spiritual fulfillment, or social cohesion experiences.
- Regulating contributions capture the functional and structural aspects of organisms and ecosystems that alter environmental conditions affecting people and help manage the production of both material and nonmaterial contributions. Some examples of this include climate regulation, water filtration, and air quality regulation.

Culture is embedded across all three categories in the NCP framework, unlike the ES framework, where it is confined to an isolated category (cultural services). This central role that culture plays in defining links between people and nature elevates, emphasizes, and operationalizes the role of indigenous and local knowledge in understanding nature's contributions to people. It is also acknowledged that the 18 categories do not fit into a single group and that the non-material and material contributions are often interlinked in most cultural contexts. For example, food is a material NCP as it provides physical sustenance, but food is full of symbolic meaning in many cultures (Díaz et al., 2018).

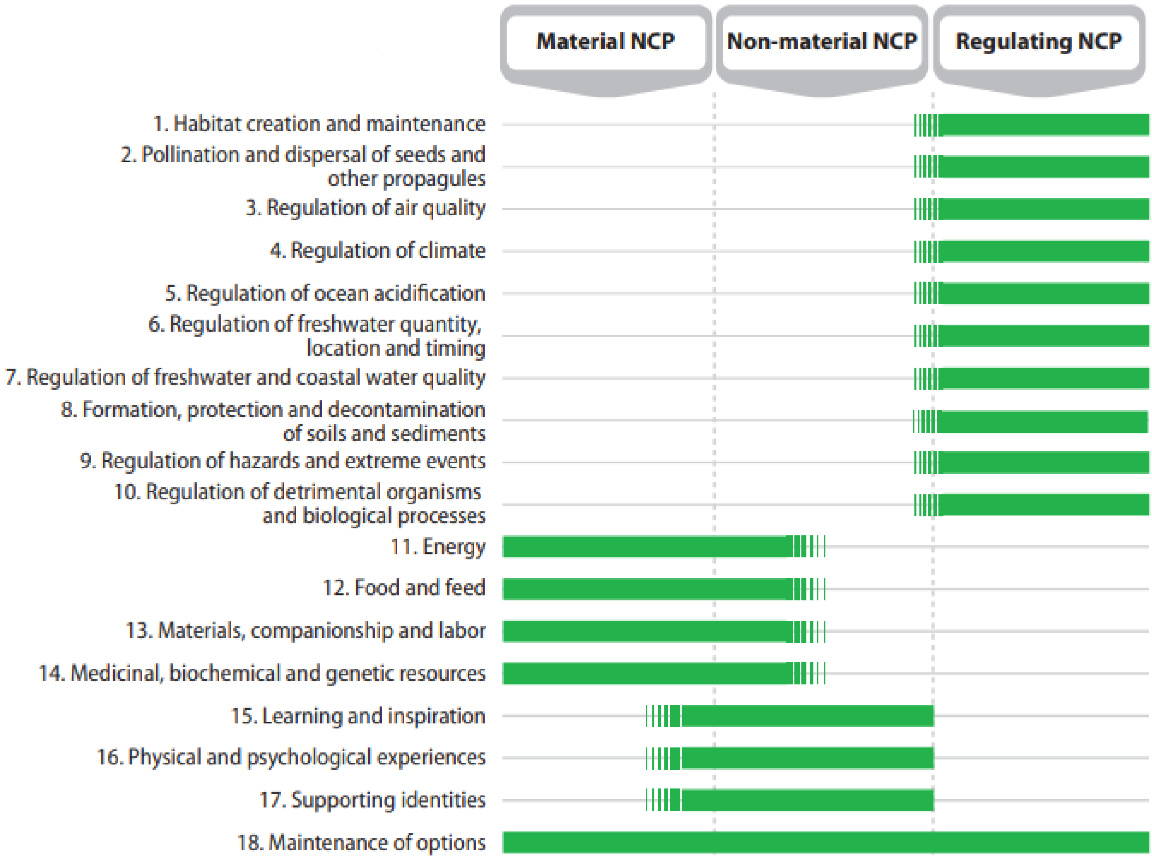

Figure 3: Nature's contributions to people framework, the 18 reporting categories of the generalizing perspective (Díaz et al., 2018).

2.4.2. Context-specific perspective

The context-specific perspective typically (but not exclusively) reflects local and indigenous knowledge systems. This perspective acknowledges that there are multiple ways of understanding and categorizing relationships between people and nature. This avoids leaving these perspectives out of the picture or forcing them into the 18 generalizing NCP categories (Díaz et al., 2018). The role of culture in the NCP framework sets the potential for a wider set of viewpoints and stakeholders and moves away from nature's contributions that are only experienced in economic value. The NCP approach thus promotes respectful collaboration across different knowledge systems, enabling the co-creation of knowledge for sustainability (Díaz et al., 2018).

2.5. Differences and similarities between ES and NCP

This section clarifies the similarities and differences between ES and NCP. Drawing from Kadykalo et al. (2019) and Díaz et al. (2018), and by examining both frameworks at a conceptual level.

Kadykalo et al. (2019) examined NCP's conceptual claims and assessed whether these ideas were already present in ES literature. They found that six conceptual claims in NCP had familiarity in ES research, which is expected given that NCP builds upon ES. These claims include culture, social sciences and humanities, indigenous and local knowledge, negative contributions of nature, generalizing perspectives, and non-instrumental values and valuation. For instance, while ES research often focuses on cultural ecosystem services, NCP may overlook rare ES studies that integrate culture across multiple dimensions. Similarly, ES research has made progress in engaging social sciences and humanities. Indigenous and local knowledge, while acknowledged, is still underrepresented in ES literature. Although ecosystem disservices receive less attention than ES benefits, the recognition of negative contribution of nature is not exclusive to NCP. Emerging approaches in ES literature incorporate non-instrumental values and valuation (socio-economic and non-monetary), yet biophysical and economic frameworks still dominate. Lastly, there is a big overlap in the generalizing perspective of NCP with ES classifications (Kadykalo et al., 2019).

However, Kadykalo et al. (2019) identified five areas where NCP presents novelty in people-nature relations: context-specific perspective, diverse worldviews, relational values, fuzzy and fluid reporting categories and groups, inclusive language and framing. The context-specific perspective recognizes that local or cultural worldviews derive meaning from their specific socio-cultural and ecological contexts and are not necessarily universal, distinguishing them from the standardized approach of the formal ES framework. The ES framework also mostly embraces western-scientific worldviews, which is something NCP is trying to diversify. NCP has the potential to incorporate a broader range of value types beyond instrumental and intrinsic values, providing opportunities to explore relational values of nature, which have not been covered much in ES literature. NCP categories are more flexible, whereas ES tends to have discrete and rigid categorization. Additionally, NCP's inclusive language and framing enhance its role as a communication tool, bridging gaps where ES has struggled as a common language or 'boundary object' (Kadykalo et al., 2019). NCP re-frames ES concepts in two key ways: shifting from 'services' to 'contributions' and from 'well-being' to 'quality of life.' While these conceptually align, these terms carry different connotations and aim to broaden the scope of people-nature relations (Kadykalo et al., 2019).

Diaz et al. (2018) also emphasize how NCP moves away from the uniform assessment of ecosystem services, which often prioritizes economic value as the central link between people and nature. Instead, NCP emphasizes the cultural, context-specific, and subjective dimensions of nature's contributions. It recognizes that nature enhances quality of life through diverse pathways shaped by individual, collective, and cultural values. By operationalizing these connections, NCP provides a broader set of metrics that capture nature's contributions beyond material benefits, avoiding the tendency to reduce these relationships to purely economic or quantitative measures (Díaz et al., 2018).

To visualize the similarities and differences between these two frameworks, Figure 4 was created. The dashed lines in the figure illustrate how many NCP categories conceptually align with the ES classification. However, the figure also highlights differences. While the ES framework contains a single category for cultural services, NCP includes three non-material categories and recognizes that culture permeates through all 18 categories. Additionally, NCP 18: maintenance of options captures the capacity of ecosystems, habitats, or species to keep options open to support quality of life in the future, an aspect that is not explicitly addressed by the ES framework. Furthermore, NCP's context-specific perspective creates space for the inclusion of local and indigenous knowledge systems, which are not directly accommodated in the ES framework.

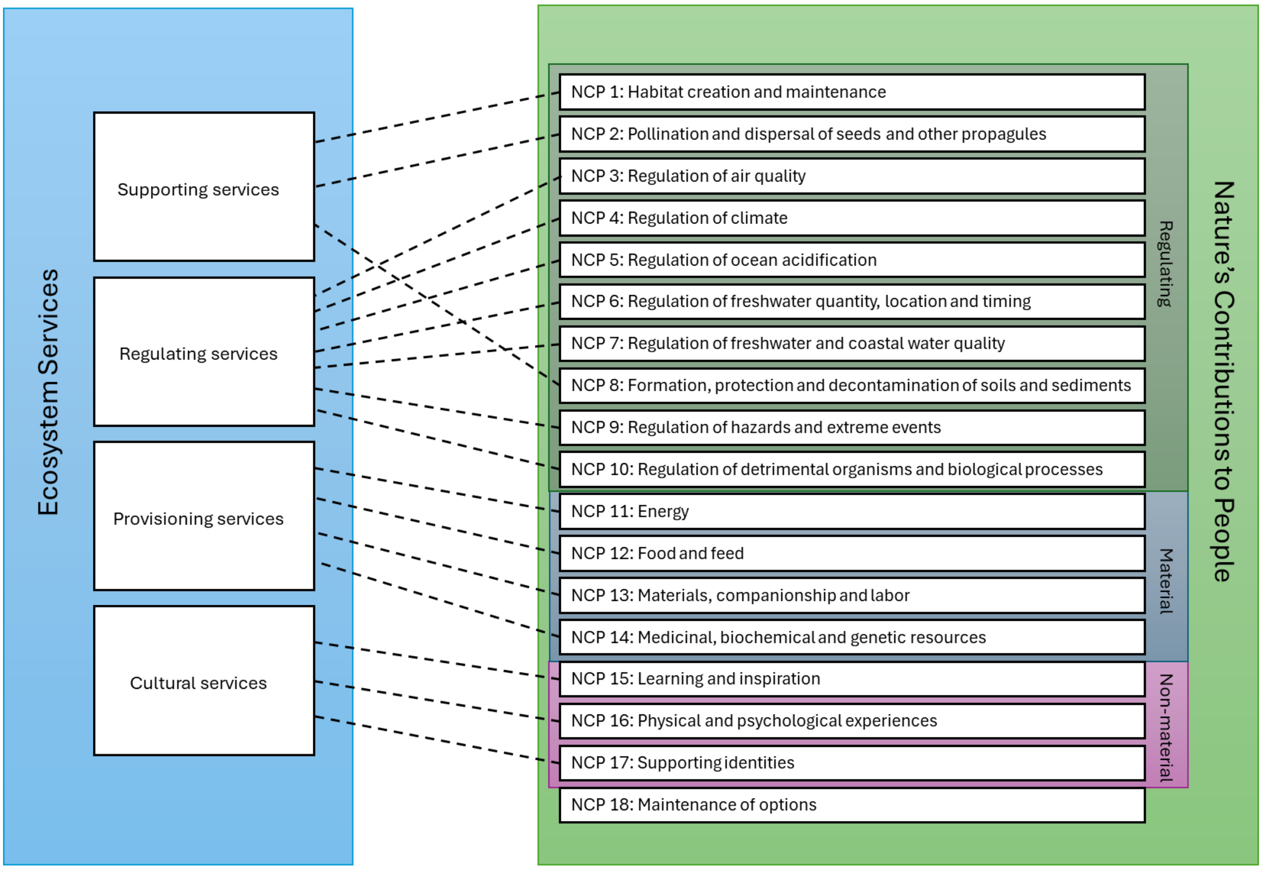

Figure 4: ES classification (MA, 2005) vs. generalizing perspective NCP (Díaz et al., 2018) (Figure made by author)

While ES research has recognized and incorporated cultural values and multiple value conceptualizations, NCP expands this by emphasizing context-specific worldviews beyond standardized assessments. In doing so, NCP advances existing ES research into broader theoretical boundaries. However, these ideas are still emerging and may lack rigorous operationalization, requiring future efforts to refine and develop them further (Kadykalo et al., 2019).

2.6. Knowledge gap

Despite the increasing recognition of NbS as a key strategy for addressing urban sustainability challenges, there remains a significant gap in its theoretical grounding, evaluation, and monitoring (Frantzeskaki et al., 2019; Bona et al., 2022). Existing NbS research has largely relied on the ES framework to assess benefits. While ES has been instrumental in linking ecosystems to human well-being and informing environmental policy, it also has notable limitations, particularly in capturing cultural, relational, and context-specific values (Kadykalo et al., 2019). These values are important for NbS in urban environments, where socio-spatial dynamics play a critical role. Without attention to cultural, relational, and context-specific values, NbS can unintentionally contribute to the displacement of local communities. For example, new NbS interventions, such as parks, may raise land prices and rent in surrounding areas, potentially displacing the populations they were designed to benefit (Grimm et al., 2023).

Taken together, these limitations suggest that although ES has contributed significantly to integrating ecological considerations into decision-making, it requires substantial adaptation or complementary frameworks to fully support inclusive, pluralistic, and context-sensitive evaluation. In response to these critiques, IPBES developed the NCP framework. NCP offers a broader and more flexible perspective that explicitly incorporates multiple types of values, knowledge systems, and worldviews, recognizing the diverse ways in which people benefit from and relate to nature (Díaz et al., 2018).

However, NCP has yet to be extensively applied in urban contexts, and its potential relevance for NbS remains underexplored. This thesis seeks to bridge this gap by investigating how the NCP framework can provide insights into the benefits of NbS in urban environments.

3. Methods

This thesis employed a mixed-method approach structured around the four SQs. SQ1: *"What existing frameworks are used to evaluate the benefits of NbS and how does the most prominent one compare with NCP?"* was addressed through a literature review described in section 2. SQ2: *"Which NCP categories are most relevant to urban environments, and how do NbS contribute to these categories?"* was answered in two steps. First, a literature review was used to identify key urban environmental challenges, which served as a filter to reduce the 18 NCP categories to 13 relevant ones. Secondly, a scoring table was developed to assess how common urban NbS contribute to these 13 NCP categories, based on three criteria, including literature evidence. SQ3: *"What indicators or proxies can be used to assess NCP in urban NbS?"* was addressed by extracting indicators from the literature and selecting a focused set (NCP 16) for spatial analysis. SQ4: *"How can the NCP framework be applied to a case study of an urban NbS and what insights does this provide?"* was answered by applying the selected indicators to a spatial analysis of Park Frankendael in Amsterdam, complementing an existing ES-based assessment. The following sections provide a detailed description of these methodological steps.

3.1. Scoping NCP categories relevant to urban environments

This section will describe the method used to answer the first part of SQ2: *"Which NCP categories are most relevant to urban environments?"* A focused literature review was conducted using databases such as Scopus and Google Scholar, supplemented by snowballing techniques. The aim was to identify key environmental challenges currently faced by cities within the European context. Search strings included the following combinations:

- "urban" AND "challenges"
- "urbanization" AND "challenges"
- "urban" AND "environmental" AND "EU" AND "challenges"

From the initial search (screening titles), approximately 60 studies were selected for abstract screening. Abstracts were reviewed based on the three criteria: their relevance to cities (urban areas), environmental challenges, and European context. If the abstract met the criteria, the full text was reviewed; otherwise, the paper was excluded. After screening around 30 abstracts, 10 relevant studies were selected that met the criteria. At this point, the environmental challenges reported across studies began to overlap, with the same five categories recurring frequently. Because further screening was unlikely to yield new insights, the review was concluded after 10 studies.

From this review, five key urban environmental challenges: pollution, climate impacts, biodiversity loss, resource management, and human well-being were identified. These five overarching urban environmental challenges were then used to systematically assess all 18 NCP categories from Díaz et al. (2018). For this, Table 2 was developed, where each NCP category is presented with:

- Definition (column 2): based on Brauman et al., 2020 and Díaz et al., 2018.
- Urban environmental challenge targeted (column 3): where each NCP was checked for its direct relevance to at least one of the five urban environmental challenges.
- Inclusion decision (column 4): If there was at least one urban environmental challenge targeted, it was included with, yes, otherwise, no.

- Explanation (column 5): describes the rationale for inclusion or exclusion of a NCP category.

This structured approach ensured transparency in reducing the NCP categories from 18 to 13 considered most applicable to urban settings.

3.2. NCP contributions of urban NbS

This section describes the method used to answer the second part of SQ2: *"how do NbS contribute to these categories?"* To illustrate the contribution of different commonly used urban NbS types to each NCP category, Table 3 was developed using the following approach:

- On the Y-axis, all 13 NCP categories were listed.
- On the X-axis, the five frequently applied urban NbS types were included. For each NbS type, two columns were added: a "Score" column and a "Comments" column.
- In the Score column, each NbS type was assigned a "low," "medium," or "high" contribution score for each NCP category.
- In the Comments column, an explanation is given on why the score was assigned.

The scoring was based on three key principles:

- Findings from the literature review
- Primary function of the NbS type versus co-benfits: for example, while rain gardens offer biodiversity benefits, their core design purpose lies in water management, meaning NCP 6 (regulation of freshwater quantity) and NCP 7 (regulation of water quality) scored higher than NCP 1 (habitat creation)
- Relative comparison across NbS types: for instance, a core function of community gardens is food provision (NCP 12), which is why this NbS type scores higher on NCP 12 relative to others.

To score how different frequently used urban NbS, specifically green roofs, rain gardens, community gardens/urban farming, blue infrastructure, and urban parks, contribute to the 13 NCP categories, a literature review was conducted using the Scopus and GoogleScholar databases. The following search strings were used:

- "NbS" AND "ecosystem services" OR "benefits"
- "NbS" (e.g. green roofs) AND "specific NCP terms" (e.g. habitat creation, air quality, pollination/seed dispersal)

After an initial title screening, around 90 studies were assessed at the abstract level. Abstracts were filtered based on the following criteria: whether they addressed urban contexts, at least one of the NbS types, and their contribution to ES or NCP. If an abstract met these criteria, the full text was reviewed; if not, the study was excluded. Following this process, 37 papers were selected for full-text review that together covered all five NbS types and provided sufficient evidence to score their contributions across the 13 NCP categories.

It should be highlighted that these scores are relative and during the process of constructing Table 3, several trade-offs emerged, indicating that the contribution of NbS to NCP is context-dependent. These trade-offs are summarized in Table 4 and underscore that NbS benefits cannot be viewed in isolation but should be interpreted within specific urban contexts.

Finally, Table 3 was used as a rationale for selecting a specific NCP category for further spatial analysis, focusing on NCP 16, which contributes to SQ4.

3.3. Identifying indicators to assess NCP in urban NbS

This section describes the method used to answer SQ3: *"What indicators or proxies can be used to assess NCP in urban NbS?"* To identify indicators that can assess NCP in urban NbS, a targeted literature review was conducted using the Scopus database and research techniques like snowballing. To find indicators/proxies that can assess NCP in urban NbS, different keywords were used. Some research strings that were used are as follows:

- "quantifying" AND "natures contribution to people"
- "urban' AND "nature based solutions" AND "social" AND "indicators"
- "assessing" AND "nature" AND "based" AND "solutions" AND "urban"
- "assessing" AND "nature" AND "based" AND "solutions" AND "urban" AND "indicator*"

After an initial title screening, approximately 80 studies were screened at the abstract level. Each abstract was reviewed for its relevance to NbS, urban contexts, NCP, related framings, and applicability to the case study park Frankendael. If an abstract addressed these criteria, the full text was reviewed; if not, the study was excluded. All 80 abstracts were screened following this process. During the full-text review, recurring indicators and overlapping themes were identified, resulting in the selection of 26 papers.

Indicators were extracted from these studies, based on relevance to urban scale, data availability, and link to NCP categories. Subsequently, these indicators were categorized by NCP category, guided by Díaz et al. (2018) and contextual interpretation based on study content. This resulted in a list of indicators per NCP category (see Appendix 8.1). From this list, a few indicators were selected based on the three criteria: (1) their ability to represent relational or context-specific values not commonly captured by ES frameworks, (2) their suitability for spatial analysis using ArcGIS, and (3) their suitability for the most promising NCP (16) in Table 3. These criteria were chosen to highlight the differences between ES and NCP and to explore the added value of the NCP framework. Ultimately, three indicators were selected, all falling under NCP 16: physical and psychological experiences. These indicators are accessibility, demographic composition, and equitable distribution of blue-green spaces.

3.4. Spatial analysis (case study)

This section describes the method used to answer SQ4: *"How can the NCP framework be applied to a case study of an urban NbS and what insights does this provide?"*. It first introduces the case study and the previous ES assessment, then the data collection, and finally provides a short description of the spatial analysis.

3.4.1. Case study description: urban park Frankendael, Amsterdam

In order to compare the ES framework with the NCP framework, the most practical approach was to select a case study of a NbS that had already been evaluated using the ES framework. Urban park Frankendael in Amsterdam, the Netherlands, was chosen for this purpose, as Alvarado (2025) conducted a comprehensive ES assessment here using the i-Tree Eco tool. This tool quantifies multiple ES through trees. Recognizing that the i-Tree Eco tool can't capture all ES, Alvarado supplemented the analysis with additional quantitative and qualitative methods, including Atlas Natuurlijk Kapitaal model, survey, interviews, literature, and site visits.

Building on this existing assessment, this analysis explores how the application of the selected NCP 16 indicators: accessibility, demographic and equitable distribution of blue-green space, can show added value of the NCP framework. Spatial analysis was chosen because it allows for replicable and objective measurement of accessibility, demographic composition, and equity distribution and is appropriate in urban settings. Additionally, the spatial analysis produces visual maps, offering effective results to communicate findings to policymakers in a clear way. This approach aims to extend the ES assessment by addressing not only what services the park provides, but also who benefits from them, who has access, and who may be excluded.

3.4.2. Data collection

For the data collection, multiple sources were used, including the NationaalGeoregister, PDOK, CBS, and the Municipality of Amsterdam. Table 1 provides an overview of the data used and their respective sources.

Table 1: Data collected with a brief description and source

Name	Brief description	Source
Wijk- en Buurtkaart 2024	Geometry of all municipalities, districts, and neighborhoods in the Netherlands, with key statistical figures as attributes.	(CBS, 2025)
CBS Vierkantstatistieken 100m ATOM	100m resolution grid data with demographic statistics for the Netherlands.	(CBS, 2024)
PARKPLANTSOENGROEN	CSV file containing coordinates of city parks, public gardens and recreational green space in Amsterdam.	(Gemeente Amsterdam, 2014)
Noord-Holland-Latest-free	Zip file with shapefiles containing the road network of North Holland, Netherlands, downloaded via Geofabrik.	(OpenStreetMap, 2025)
Bevolking 15 tot 75 jaar; opleidingsniveau, wijken en buurten, 2022	Data on the educational level of people aged 15–75 per municipality, district, and neighborhood.	(CBS, 2022)
Kerncijfers wijken en buurten 2023	Data on income per district and neighborhood in the Netherlands.	(CBS, 2023)

3.4.3. Short description of spatial analysis

The spatial analysis focused on three NCP 16 indicators (accessibility, demographic composition, and equitable distribution of blue-green spaces) and resulted in three types of maps: (1) accessibility, (2) demographic composition, and (3) equitable distribution.

First, an accessibility map was created by calculating network buffers of 300, 500, and 1000 meters from park Frankendael, following distances identified in the literature. Using the CBS 100m grid population data, the number of residents within each buffer was calculated. This assumed proximity equals access.

Second, demographic maps were developed to visualize the distribution of potentially vulnerable groups based on CBS neighborhood-level data. This resulted in eight maps:

- Age: % children, % elderly
- Income: average income per inhabitant, % low-income households
- Ethnicity: % non-European origin
- Education: % of the population with low, medium, and high levels of education

Lastly, equitable distribution maps were created to show if certain vulnerable groups have equal access to the park. This combined the accessibility buffers with the CBS 100m resolution grid data of children, elderly and non-European origin residents. This resulted in three additional maps showcasing whether children, elderly and residents with a non-European origin have equal access to the parks benefits.

A detailed description of the GIS workflow is provided in Appendix 8.2.

4. Results

In this section, SQ2 – 4 will be answered. Sections 4.1 and 4.2 describe the results of SQ2: *"Which NCP categories are most relevant to urban environments, and how do NbS contribute to these categories?"*. Section 4.3 presents the indicators identified for SQ3: *"What indicators or proxies can be used to assess NCP in urban NbS?"* and section 4.4 describes the spatial analysis of park Frankendael using the selected NCP 16 indicators answering SQ4: *"How can the NCP framework be applied to a case study of an urban NbS and what insights does this provide?"*

4.1. Scoping NCP relevant to urban environments

This section answers the first part of SQ2: *"Which NCP categories are most relevant to urban environments?"* To determine the key NCP categories most relevant to urban environments, it is important to examine the environmental challenges that cities currently face. By aligning these challenges with the NCP framework, the categories were scoped down to reflect the specific needs of urban environments. First, the urban environmental challenges identified in the literature are described, followed by an explanation of how the categories were scoped down to those most relevant to urban environments.

4.1.1. Urban environmental challenges

Urbanization has emerged as a critical driver of environmental challenges in cities. As populations continue to concentrate in urban areas, cities face population growth, rapid expansion, and densification (Twohig et al., 2022). While urbanization brings economic benefits, it has also resulted in a number of negative environmental consequences and a degradation of the quality of life in cities. This is exacerbated by the simultaneous pressures of climate change (Oertli et al., 2023).

Pollution is one of the environmental challenges faced by cities, primarily driven by anthropogenic activities (Mihalakakou et al., 2023). Cities are the largest contributors to greenhouse gases, leading to air pollution and a decline in air quality. Additionally, pollution affects soil and water, such as runoff that can bring suspended nutrients, heavy metals, pesticides, wastewater, sewage, storm water, and other pollutants (Oertli et al., 2023; Shanahan et al., 2013).

The second challenge has to do with the impacts of climate change. Climate change causes rising global temperatures. This leads to rising sea levels, increased occurrences of extreme weather events such as floods, drought, heatwaves, and storms, and an increased spread of tropical diseases (Keivani, 2009; UNEP, n.d.). This has costly consequences on cities, affecting their basic services, infrastructure, housing, livelihoods, and public health (UNEP, n.d.). In urban areas, global warming is further exacerbated by the Urban Heat Island (UHI) effect, where cities experience higher temperatures than their surrounding areas due to factors such as impervious surfaces, heat-retaining infrastructure, and limited green spaces (Mihalakakou et al., 2023).

Biodiversity loss is another challenge cities face as they expand and develop (Mihalakakou et al., 2023; Oertli et al., 2023). Urbanization transforms natural ecosystems. Often it leads to habitat changes, including the replacement of vegetated surfaces with impervious materials and the conversion of natural vegetation or agricultural land into urban parks or private gardens. Additionally, the dense human occupation of urban landscapes intensifies these impacts, further disrupting natural ecosystems (Shanahan et al., 2013).

Furthermore, there is the challenge of resource management, specifically water management and security (Keivani , 2009; Oertli et al., 2023; Veerkamp et al., 2021). Currently, cities are responsible for producing 50% of global waste and 75% of energy and natural resource consumption (Bona et al., 2022). This increases pressure on rural areas and natural ecosystems to supply water, energy, food and to handle waste (Bona et al., 2022). Simultaneously, there is a loss of agricultural land arising from urbanization, urban sprawl and industrial activities (Keivani, 2009).

Lastly, the quality of life for human well-being is a challenge. Urbanization and climate change cause the degradation of public health and well-being (Mihalakakou et al., 2023; Veerkamp et al., 2021) via the aforementioned challenges. Residents often lack access to green spaces for recreation and there is excessive noise (Mihalakakou et al., 2023; Richards et al., 2022). Urbanization impacts mental health by introducing a range of stressors, including overcrowded and polluted environments, heightened levels of violence, and diminished social support (Srivastava, 2009).

To summarize this section, urbanization causes five overarching urban environmental challenges: pollution, climate impacts, biodiversity loss, resource management and human well-being.

4.1.2. NCP categories relevant to urban environments

This section answers the first part of SQ2: *"Which NCP categories are most relevant to urban environments?"*. The NCP categories relevant to urban environments were scoped down using the urban environmental challenges derived from literature: pollution, climate impacts, biodiversity loss, resource management, and human well-being, as a lens. Each of the 18 original NCP categories (Díaz et al., 2018) was evaluated for its potential to directly address one or more of these urban environmental challenges. This filtering ensures that only the NCP categories that reflect the needs of urban environments remain, making the subsequent analysis more targeted.

Table 2 presents this assessment, with green rows indicating included NCPs and red rows indicating those excluded from further analysis. Each row indicates which urban environmental challenge(s) are addressed by the respective NCP category and provides a brief justification for its inclusion or exclusion from further analysis.

Table 2: NCP categories relevant to urban areas.

NCP category		Definition of NCP category (Brauman et al., 2020; Díaz et al., 2018)	Urban environmental challenge targeted	Included?	Why relevant?
NCP 1	Habitat creation and maintenance	The creation and ongoing production of ecological conditions necessary or favorable for living beings important to humans.	Biodiversity loss	YES	Relevant to urban areas as it promotes biodiversity by creating habitats through e.g. urban parks and trees.
NCP 2	Pollination and dispersal of seeds and other propagules	The process by which animals assist the movement of pollen between flowers and the dispersal of seeds, larvae or spores of organisms that can either benefit or harm humans.	Biodiversity loss	YES	Relevant category for biodiversity in urban areas and play a supporting role with urban farming.

NCP 3	Regulation of air quality	Filtration, fixation, degradation or storage of pollutants and gases that affect human health or infrastructure (e.g., CO2/O2 balance, O3, sulphur oxide, nitrogen oxides (NOx), organic compounds (VOC), particulates, aerosols, and allergens).	Pollution, Human well-being	YES	Relevant to urban areas to combat air pollution, which will also help enhance public health.
NCP 4	Regulation of climate	Climate regulation by ecosystems through emissions and sequestration of greenhouse gases, biophysical feedbacks from vegetation cover to atmosphere (e.g., albedo, surface roughness, long-wave radiation, evapotranspiration, and cloud formation), and processes involving biogenic volatile aerosol compounds (BVOC) and aerosols.	Climate impacts, Human well-being	YES	Relevant to urban areas because they are affected by climate change. This is important to mitigate greenhouse gases and UHI effect.
NCP 5	Regulation of ocean acidification	Regulation of atmospheric CO2 concentrations and so seawater pH by photosynthetic organisms on land or in water.	-	NO	Not relevant to urban areas as it is not directly linked to urban challenges. This is more relevant for marine ecosystems.
NCP 6	Regulation of freshwater quantity, location and timing	Regulation of the quantity, location, and timing of the flow of surface and groundwater by ecosystems	Resource management	YES	Relevant to urban areas, as they face problems with water management and help with flood prevention.
NCP 7	Regulation of freshwater and coastal water quality	Regulation by ecosystems of the quality of water used directly or indirectly, through filtration of particles, pathogens, excess nutrients, and other chemicals	Resource management	YES	Relevant for urban areas to filter pollution and manage the water quality.
NCP 8	Formation, protection and decontamination of soils and sediments	The formation and long-term maintenance of soil structure and fertility by plants and soil organisms, including erosion prevention, nutrient cycling, organic matter supply, and pollutant filtration or storage.	Pollution, Resource management, Biodiversity loss	YES	Relevant for urban areas through pollution, water management and biodiversity.
NCP 9	Regulation of hazards and extreme events	Improvement of the impacts on humans or their infrastructure caused by hazards.	Climate impacts, Human well-being	YES	Relevant as urban areas struggle and are impacted by the increased amount of extreme weather events and hazards due to climate change.
NCP 10	Regulation of detrimental organisms and biological processes	Regulation of pests, pathogens, predators, parasites or competitors that affect humans, or plants or animals important to humans.	-	NO	Not relevant to the urban environmental challenges.
NCP 11	Energy	Production of biomass-based fuels (e.g., biofuel crops, animal waste, fuelwood, agricultural residue pellets and peat).	-	NO	Although energy is important to urban areas, most cities are moving towards renewable energy infrastructure and not biomass production.
NCP 12	Food and feed	Production of food and feed from wild, managed or domestic organisms.	Resource management	YES	Relevant to urban areas through resource management. It will

					alleviate some of the pressure on rural areas to produce food.
NCP 13	Materials, companionship and labor	Cultivated or wild materials and direct use of living organisms for industrial, construction, clothing printing, ornamental, company, transport and labor (including herding, searching, guidance, guarding).	-	NO	Applies more to the rural contexts.
NCP 14	Medicinal, biochemical and genetic resources	Production of materials derived from organisms used for medicinal, veterinary and pharmacological purposes. Production of genes and genetic information.	-	NO	Production for medicinal use is not often done in urban areas.
NCP 15	Learning and inspiration	The provision of opportunities by natural landscapes, habitats, or organisms for education, knowledge acquisition, development of skills for well-being, information, and inspiration for art and technology.	Human well-being	YES	Relevant to people living in urban areas.
NCP 16	Physical and psychological experiences	The provision of opportunities by natural landscapes, habitats or organisms for physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, tourism and aesthetic enjoyment.	Human well-being	YES	Relevant to people living in urban areas.
NCP 17	Supporting identities	Provision of opportunities by natural landscapes, habitats or organisms for religious, spiritual and social-cohesion experiences. Includes a sense of place, belonging, or rootedness associated with the living world; narratives, rituals and celebrations; satisfaction derived from knowing a landscape, seascape, habitat or species exists.	Human well-being	YES	Relevant to people living in urban areas.
NCP 18	Maintenance of options	Capacity of ecosystems, habitats, or species to keep options open to support quality of life in the future.	Human well-being, Climate impacts	YES	Has to do with the flexibility of the interventions. This category can show the relevance of how an intervention can serve multiple purposes.

Out of the 18 original NCP categories, 13 were deemed relevant to urban areas. Notably, most material NCP categories (NCP 11: energy, NCP 13: materials, companionship and labor, NCP 14: medicinal, biochemical and genetic resources) were excluded, along with two regulating NCP categories (NCP 5: regulation of ocean acidification and NCP 10: regulation of detrimental organisms and biological processes). The resulting selection is primarily composed of regulating and non-material NCP categories, including one material NCP. Excluded categories predominantly addressed processes less critical in urban contexts, such as marine ecosystem functions (NCP 5) or large-scale biomass energy production (NCP 11). In general, these excluded categories were also considered less relevant for evaluating urban NbS.

All non-material NCP categories were considered relevant, as they directly address cultural dimensions. These are significant in urban environments characterized by diverse populations.

Regulating NCPs also features prominently, reflecting the acute relevance of climate adaptation, pollution mitigation, and urban sustainability goals.

This refined set of 13 NCP categories provides a focused analytical lens for assessing NbS in urban areas, ensuring alignment with the key urban environmental challenges faced by cities. These categories form the basis for addressing the second part of SQ2 as well as SQ3.

4.2. NCP contributions of urban NbS

This section addresses the second part of SQ2: *"How do NbS contribute to these categories?"*. To answer this question, Table 3 has been developed. This table scores the contribution of commonly used urban NbS types to each of the selected 13 NCP categories. Contribution levels are ranked as low (red), medium (yellow), or high (green). The scores are based on the principles described in method section 3.2.

Table 3: Scoring NCP contribution of commonly used urban NbS

Urban NbS → / NCP category ↓		Green roofs		Rain gardens		Community gardens/urban farming		Blue infrastructure (wetlands, water retention systems (ponds, permeable surfaces))		Urban parks	
		Score	**Comments**	**Score**	**Comments**	**Score**	**Comments**	**Score**	**Comments**	**Score**	**Comments**
NCP 1	**Habitat creation and maintenance**	Medium contribution	Habitat for plants and insects. Connectivity of nature for wildlife (e.g., birds) in urban areas (Köhler & Ksiazek-Mikenas, 2018). The diversity of plants depends on substrate depth (Madre et al., 2013)	Medium contribution	Rain gardens can provide/improve food and shelter for wildlife, natural vegetation and biodiversity. This depends on vegetation type and immediate local context (Bąk & Barjenbruch, 2022).	Medium contribution	Provide habitat for biodiversity (Baniasadi & Eydipour, 2024; Cabral et al., 2017; Middle et al., 2014	Medium contribution	Provide habitat for species and foster biodiversity (high biodiversity value in terms of aquatic macroinvertebrates) (Kati & Jari, 2015; Krivtsov et al., 2022)	High contribution	Provides habitat "mixed forest provided the highest amount of habitat quality" (Mexia et al., 2017)
NCP 2	**Pollination and dispersal of seeds and other propagules**	High contribution	Green roofs can support pollinator populations in cities (such as bees), depending on substrate type/depth and plants used (Dusza et al., 2020; Jacobs et al, 2023). Increased connectivity through green roofs also helps pollinators (Wu, 2019)	Medium contribution	Co-benefit of rain gardens could provide pollinator habitat (Remme et al., 2024)	High contribution	Urban community gardens have the potential to play an important role in pollinator conservation, though their abundant floral resources (Makison et al., 2016). This does depend on the design of the community garden, like the vegetation used.	Medium contribution	Water bodies are important for insect biodiversity, but this depends on depth, size, type of vegetation and coverage (Bowler et al., 2024).	High contribution	Impact on seed dispersal depends on vegetation design (e.g., potential is higher in lawns than trees). Also, visitors to the park may influence the contribution as animals can be sensitive to human presence (Mexia et al., 2017)
NCP 3	**Regulation of air quality**	Medium contribution	Improve air quality, reduce particulate matter, O3, SO2, NO2 and CO2 sequestration (Mihalakakou et al., 2023). More impact when there is a more widespread implementation.	Medium contribution	Air quality improvement through plants (Bąk & Barjenbruch, 2022)	Medium contribution	They improve air quality, CO2 reduction (Dubová & Macháč, 2019).	High contribution	Urban water bodies and wetlands play a big role in carbon sequestration and long-term storage of atmospheric CO2 (Ghosh et al., 2017)	High impact	The impact is high for all vegetation types, but slightly higher for mixed forests. Carbon sequestration is positively influenced by tree density (Mexia et al., 2017).
NCP 4	**Regulation of climate**	Medium contribution	Contributes to carbon sequestration through photosynthesis and evapotranspiration (Mihalakakou et al., 2023)	Medium contribution	Rain gardens sequester carbon and can help in controlling the local climate (Bąk & Barjenbruch, 2022; Remme et al., 2024)	Medium contribution	They can regulate local climate, and CO2 emissions are reduced (Cabral et al., 2017; Dubová & Macháč, 2019)	High contribution	Urban water bodies and wetlands are natural carbon sinks, help mitigate global warming and greenhouse gas emissions (Ghosh et al., 2017)	High contribution	Green areas affect microclimate, reduce the UHI, and indirectly reduce CO2 emissions (Mexia et al., 2017)
NCP 6	**Regulation of freshwater quantity, location and timing**	Medium contribution	Has the capability to retain water (also in a cold climate (Kuoppamäki, 2021)), but depends on GR type, substrate depth, vegetation species, plant size and rainfall duration/intensity (Mihalakakou et al., 2023). Conventional GR have been criticized for its limited water buffer capacity during extreme rainfall events and vulnerability to droughts when additional irrigation is unavailable (Busker et al., 2021).	High contribution	This is one of the most prominent benefit of rain gardens. They hold and infiltrate runoff and can address excess stormwater through bioretention (Remme et al., 2024). A possible drawback is the surface requirement (depending on the type of soil, up to more than half of the drainage area) (Bąk & Barjenbruch, 2022).	Medium contribution	They regulate water and runoff, intercept and infiltrate rainwater (Cabral et al., 2017; Middle et al., 2014)	Medium contribution	Help with mitigating urban (stormwater) runoff (Kati & Jari, 2015).	High contribution	Vegetation in urban parks reduces runoff (Mexia et al., 2017)
NCP 7	**Regulation of freshwater and coastal water quality**	Medium contribution	Improves runoff water quality (Mihalakakou et al., 2023)	High contribution	Rain gardens can remove pollutants from water through the soil and plants (Bąk & Barjenbruch, 2022; Remme et al., 2024).	Medium contribution	They improve water quality (Dubová & Macháč, 2019)	High contribution	Wetlands, ponds, and permeable pavements help with the purification of water (Kati & Jari, 2015; Xie et al., 2018)	Medium contribution	Water purification through vegetation. Vegetation and soil can filter urban effluents, reducing pollutants and nutrient levels, which is essential for maintenance of groundwater quality (Mexia et al, 2017)
NCP 8	**Formation, protection and decontamination of soils and sediments**	Low contribution	Soil formation takes place within the growing medium of extensive roof greening, while its development enhances urban biodiversity and mitigates habitat loss (Schrader & Böning, 2006).	Medium contribution	Raingardens filter sediment and uptake of nutrients through soil (Remme et al., 2024).	Medium contribution	Community gardens help with erosion reduction (Dubová & Macháč, 2019)	Low contribution	Could not find something relevant	Medium contribution	More vegetation retains sediments and stabilizes soils (Mexia et al., 2017)
NCP 9	**Regulation of hazards and extreme events**	High contribution	GR can regulate the runoff water volume, which contributes to flood mitigation. Additionally, they help mitigate the urban heat island effect through evapotranspiration (Klein & Coffman, 2015; Mihalakakou et al., 2023).	Medium contribution	It can help with flood mitigation. A more widespread implementation will be more effective than a single rain garden. They can also help with mitigating UHI (especially if replacing a paved surface) Remme et al., 2024).	Low contribution	Community gardens can be helpful with flood mitigation through water interception and infiltration (Middle et al., 2014)	Medium contribution	It can help with flood prevention if strategically placed (Plieninger et al., 2022). UHI mitigation (Xie et al., 2018).	Medium contribution	More vegetation prevents landslides and floods (Mexia et al., 2017)

NCP 12	**Food and feed**	Low contribution	Most traditional green roofs are not designed for food production, but it is possible and could contribute to local food demand. A thicker soil layer and heavy plants would be needed and could give an excessive weight, which some roofs can't support. Additionally, improper use of fertilizer could affect water quality (Cristiano et al., 2020).	Low contribution	Raingarden functionality can be expanded to vegetable production, but most raingardens are not designed for it (Richards et al., 2015).	High contribution	Community gardens produce food/crop (Baniasadi & Eydipour, 2024; Middle et al., 2014)	Low contribution	Most are not designed with food production in mind	Low contribution	Depending on the design of the park, the contribution can be lower or higher. Assumed that most urban parks don't produce food.
NCP 15	**Learning and inspiration**	Low contribution	GR can be used in an educational context for children growing up in urban environments, to familiarize with outdoor spaces (Cristiano et al., 2020). This does depend on access to the green roofs.	High contribution	Raingardens can be used for educational activities. Richards et al. (2015) did this by connecting a climate science curriculum to the development and installation of 2 rain gardens where the students could particpate	High contribution	Gardening represents a very effective mechanism for ecological education in urban areas (Middle et al., 2014). Provides agricultural education/knowledge (Baniasadi & Eydipour, 2024). It can give an informal context for knowledge generation about gardening and appreciation for urban and nearby nature (Truong et al., 2022).	Medium contribution	Enjoyment of nature and can be educational (Kati & Jari, 2015)	High contribution	Urban parks can give a unique opportunity to learn about nature (Derek et al., 2025). It can give hands-on learning experiences (Ellis & Schwartz, 2016)
NCP 16	**Physical and psychological experiences**	High contribution	GR have relatively high perceived restorativeness, sensory experiences and provide added aesthetic value (Cristiano et al., 2020; Mesimäki et al., 2018). It can provide a refuge of peace and tranquility in urban centers with less noise and pollution, contributing to psychological and physical health (Mesimäki et al., 2018).	High contribution	They improve the aesthetics and benefit human health (Bąk & Barjenbruch, 2022).	High contribution	Community gardens address the extinction of important natural experiences in cities (Middle et al., 2014). Regardless of the activity undertaken in the community gardens, they are effective urban nature for providing restorative services (Middle et al., 2014). Improve health, recreation and aesthetic value (Dubová & Macháč, 2019)	Medium contribution	Can be used for outdoor recreation, restoration, relaxing and tourism (Kati & Jari, 2015; Plieninger et al., 2022)	High contribution	They serve as a source of relaxation, have positive impacts on health, and increase the effect of physical activity/recreation. Can play an important role in attracting tourists (Sadeghian & Vardanyan, 2013)
NCP 17	**Supporting identities**	Low contribution	Can give a perceived suitability of the place for oneself and the urban context (Mesimäki et al., 2018).	Medium contribution	When used as community projects, raingardens can bring people together (Bąk & Barjenbruch, 2022).	High contribution	They promote social cohesion, contribute to social capital, enhance well-being, and cultivate sense of community (Truong et al., 2022).	Medium contribution	Blue infrastructure can contribute to sense of place and aesthetic values (Plieninger et al., 2022)	High contribution	Urban parks have been perceived as an important part of community development. Facilitate social cohesion by creating space for social interaction (Sadeghian & Vardanyan, 2013)
NCP 18	**Maintenance of options**	Medium contribution	Green roofs have a high multifunctionality and could be adapted to change if necessary in the future.	Medium contribution	Rain gardens are flexible in size, shape, and land use context (Remme et al., 2024). They are also multifunctional.	High contribution	Have multiple uses, food production, social space, help prevent floods, and combat climate change	Low contribution	Multifunctional, but not easily adaptable or changed	High contribution	Can be used for multiple functions

Community gardens stand out in their high contribution to NCP 12: food and feed and non-material NCP, highlighting their role in food provision and community building. Blue infrastructure showed a high contribution in regulating NCP. Rain gardens performed well in water-regulating and social NCPs. Green roofs contribute most notably to biodiversity (NCP 1 and 2), hazard regulation (NCP 9) and aesthetics (NCP 16). Among all NbS types, urban parks demonstrated the highest overall contribution across NCP categories, indicating strong multifunctionality. However, like most other NbS types, they score low on NCP 12, as food is not a primary function in their design.

In fact, NCP 12: food and feed scores the lowest overall, as food provision is not a primary function for all NbS types, except for community gardens, where even then it is not the main purpose. This reflects the limited emphasis on food production in urban NbS. Most of the NbS types show high contributions to non-material NCP categories, with NCP 16: physical and psychological experiences scoring the highest overall. This underscores their importance in urban environments by offering restorative, recreational and cultural value, which is relevant in serving diverse populations. Given this high overall contribution, NCP 16 is especially interesting for further exploration in the case study.

During the development of Table 3, the following trade-offs were identified per NbS, presented in Table 4.

Table 4: Identified NbS trade-offs

NbS	Trade-offs
Green roofs	Limited food production, structural weight concerns, often inaccessible to public (low social impact), effectiveness depends green roof type, substrate depth, vegetation type, and widespread implementation.
Rain gardens	Space-intensive, limited food potential, effectiveness depends on vegetation type, soil type, and widespread implementation.
Community gardens/urban farming	Requires active management and community involvement, effectiveness depends on the design of the NbS (e.g., vegetation type)
Blue infrastructure	Limited food potential, effectiveness depends on depth, size, type of vegetation and coverage.
Urban parks	Typically low in food production, impact is highly dependent on design, maintenance, and vegetation diversity.

The analysis demonstrates that no single NbS is perfect across all NCP categories. Each NbS type brings distinct strengths and limitations. A consistent theme emerging from the trade-offs is that context matters: the design, scale, requirements, and implementation strategy of an NbS influence its effectiveness in delivering specific NCP. This scoring approach provides a comparative, qualitative overview and can inform urban planning by showing where specific NbS types are best suited to address local priorities.

4.3. Identified indicators to assess NCP in urban NbS

This section answers SQ3: *"What indicators or proxies can be used to assess NCP in urban NbS?"* As outlined in the methodology, a targeted literature review was conducted to identify indicators for assessing NCP in urban NbS. The full list of identified indicators is provided in Appendix 8.1. As not all NCP categories could be analysed in the time frame of this thesis, the focus was narrowed to NCP 16: physical and psychological experiences. This choice was based on the findings in Table 3, which indicated that NCP 16 had the highest contribution across all selected urban NbS types. Additionally, its selection was motivated by the feasibility of spatial analysis and the emphasis on relational and context-specific values of nature, aspects often underrepresented in ecosystem services frameworks.

In Table 5, the identified indicators for NCP 16 are presented. From this list, three indicators were selected for application in the case study (shown in bold): accessibility (Connop et al., 2020; Camacho-Caballero et al., 2024; Kato-Huerta & Geneletti, 2022; Dong et al., 2025; Kabisch et al., 2016; Ommer et al., 2022), demographic composition (Kato-Huerta & Geneletti, 2022) and equitable distribution of blue-green space (EC, 2021). These indicators were chosen based on their suitability for spatial analysis and ability to represent relational and context-specific values. The selected indicators form the basis for answering SQ4, which is discussed in the next section.

Table 5: Identified indicators for NCP 16

Indicator/proxies	**Sources**
# of visitors, # of people using NbS	(Connop et al., 2020) (Kabisch et al., 2016) (Veerkamp et al., 2021) (EC, 2021)
Presence of walking paths (walkability)	(Connop et al., 2020) (Tudorie et al., 2020) (EC, 2021)
Type of surounding roads	(Connop et al., 2020) (EC, 2021)
Type of surrounding buildings	(Connop et al., 2020)
Land use/land cover data	(Connop et al., 2020)
# of events promoting cultural beneftis	(Connop et al., 2020)
Accessibility: areas with accessibility to NbS at less than 300m, 1000m and more then 1000m, minimum distance to NbS, # and share of people with access to NbS vs # of residents affected by displacement, average distance of NbS from urban centres/train station/public transport (km), NbS proximity to population	**(Connop et al., 2020) (Camacho-Caballero et al., 2024) (Kato-Huerta & Geneletti, 2022) (Dong et al., 2025) (Kabisch et al., 2016) (Ommer et al., 2022)**
NbS area (area in relation to population, area per captia). Area (m2), Size (ha)	(Connop et al., 2020) (Kato-Huerta & Geneletti, 2022) (Kothencz & Blaschke, 2017) (EC, 2021) (Ommer et al., 2022)
Noise attenuation: day-evening-night noise level, average leaf biomass, canopy area of trees and hedges	(Nature4Cities, 2017) (Tudorie et al., 2020) (Ommer et al., 2022)
Safety: percentage of gender violence, percentage of victimization, number of deaths and missing people, criminal report in the area, number of violent incidents, nuisances and crimes per 100.000 population	(Nature4Cities, 2017) (Kato-Huerta & Geneletti, 2022) (EC, 2021) (Watkin et al., 2019)
Perceived health, self-rated health and life satisfaction	(Nature4Cities, 2017) (Kato-Huerta & Geneletti, 2022)
aesthetic value: Number of houses bordering natural areas # users of “scenic routes”	(De Groot et al., 2009)
Population density (inhabitants/area)	(Camacho-Caballero et al., 2024) (Dong et al., 2025)
Demographic composition	**(Kato-Huerta & Geneletti, 2022)**
Property value	(Kato-Huerta & Geneletti, 2022) (La Rosa et al., 2015) (Watkin et al., 2019)
%/area of vegetated surfacs, %/area of water surface	(Kothencz & Blaschke, 2017) (La Rosa et al., 2015)
# of recreation events, increase in # of people engaged in sports, increased physical outdoor activity	(Kabisch et al., 2016) (Veerkamp et al., 2021) (Watkin et al., 2019) (Tudorie et al., 2020)
Socioeconomic data: schooling, unemployment, employment type and percentage of population with chronic illness, age, disability	(Dong et al., 2025) (Balzan et al., 2021)
Deprivation index: Ratio of the number of inhabitants with below-average income per unit area to the total population of the region	(Dong et al., 2025)

Average income (average income of inhabitants per unit area	(Dong et al., 2025)
Surrounding greenness (area NDVI >0.18)	(Langemeyer et al., 2019) (Kothencz & Blaschke, 2017)
Health benefits (monetery): avoided treatment expenditure, avoided income loss	(Jegatheesan et al., 2022)
Health: incidence of cardiovascular disease (% per year), incidence of obesity (%/year), incidence of chronic stress (%/year), prevalence of autoimmunie diseases (%), reduced heat stress (UTCI), air quality improvement	(EC, 2021) (Ommer et al., 2022)
Mental health: reduced depression and anxiety, attention restoration, recovery from stress	(Tudorie et al., 2020):
Visual acces to green space	(EC, 2021)
Proportion of elderly resident (%)	(EC, 2021)
Stakeholder involvement in co-creation/co-design of NbS (#), diversity of stakeholders involved (%)	(EC, 2021)
Perception green space based on surroundings outside NbS: Number of building units, % of built up area, building height variation in a 50 m buffer zone around the NbS	(Kothencz & Blaschke, 2017)
Availability and equitable distribution of blue-green space (map)	**(EC,2021)**

4.4. Applying selected NCP indicators to park Frankendael, Amsterdam (case study)

This section addresses SQ4: *"How can the NCP framework be applied to a case study of an urban NbS and what insights does this provide?"* by presenting the results of applying the NCP 16 indicators to the urban park Frankendael in Amsterdam. First, a summary is provided of the existing ES assessment of park Frankendael conducted by Alvarado (2025). This is followed by the case study results of the three applied indicators: accessibility, demographic composition, and equitable distribution of blue-green space.

4.4.1. Summary of existing ES assessment park Frankendael

Alvarado (2025) conducted an ES assessment of Park Frankendael in Amsterdam, aiming to capture the range of benefits the park provides. These include biophysical regulation to cultural and recreational values. To achieve this, a value case was developed as the final output, synthesizing both quantitative and qualitative data as well as financial and non-financial aspects.

The core of the assessment relied on the i-Tree Eco tool. This is a standardized model developed to evaluate a range of ES from trees. The ES measured by the i-Tree eco tool include: carbon storage and sequestration, air pollution removal, oxygen production, avoided stormwater runoff, and structural value. Additional ES relevant to the urban context, but can't be captured by i-Tree Eco, were assessed through ad-hoc methods, such as the Natural Capital model developed by the Dutch National Institute for Public Health and the Environment, surveys, site visits, interviews, literature values, spatial unit value transfer approach and economic calculations. The ES measured with the ad-hoc measurements include: cooling effect, mobility, education, revenue and income, and recreation, aesthetic and spiritual services. The key findings and outcomes of the park Frankendael value case are shown in Table 6.

Table 6: Key findings and outcome of the park Frankendael value case with respective methods used (Alvarado, 2025)

Category	Ecosystem service	Quantity	Value	Method
Regulating (air quality)	Air pollution removal	664.4 kg	€32,600 per year	i-Tree Eco tool
	Oxygen production	73.55 metric tons per year	-	i-Tree Eco tool
	Volatile organic compounds (VOCs) (disservice)	134.7 kg per year	-	i-Tree Eco tool
Regulating (climate change)	Carbon sequestration	27.58 metric tons per year	€5560 per year	i-Tree Eco tool
	Carbon storage	3430 metric tons	€696,000	i-Tree Eco tool
Regulating (water management)	Avoided runoff	2,307 m3 per year	€21,800 per year	i-Tree Eco tool
Regulating (temperature)	Local cooling effects	Daily average reduction of 1.6–2.4°C		Natural Capital Model
Cultural (economic)	Structural value	-	€9.69 million	i-Tree Eco tool
	Municipal income from community garden	-	€64,000 per year	Economic calculation
Cultural (aesthetic)	Aesthetic value of natural elements of the park	-	€107,770 (combined) per year	Survey, interviews, site visits, and spatial unit value transfer approach
Cultural (recreation)	Opportunities for leisure and space for events	-	-	Survey, interviews, site visits, and spatial unit value transfer approach
Cultural (spiritual)	Spiritual enrichment associated with natural elements of the park	-	-	Survey, interviews, site visits, and spatial unit value transfer approach
Cultural (education)	School gardens and scouting activities	500 children involved in gardening; 90+ children participating in weekly scouting activities at the park	-	Literature values
Cultural (mobility)	Transit routes for pedestrians and cyclists	Higher safety and increased contact with nature	-	Site visits
Total economic value (per year)	-	-	€231,730	-

This summary highlights the park's multiple benefits to society, forming a foundation for the NCP-based analysis carried out in this thesis. Building on this ES assessment, the following section applies selected NCP 16 indicators to explore the added value of the NCP framework.

4.4.2. Results of the NCP 16 indicators

This section presents the results of the selected NCP 16 indicators, which were applied using ArcGIS. The indicators are accessibility, demographic composition, and equitable distribution of blue-green space.

4.4.2.1. Accessibility

The accessibility was measured by calculating the population living within walking distance of park Frankendael, using network buffers of 300m, 500m, and 1000m. Population data from a 100m resolution grid was used for this analysis. Figure 5 presents the accessibility map and visualizes the buffer zones and corresponding population counts.

Accessibility:
Population within Network Bufffers (300m, 500m, and 1000m) of Park Frankendael

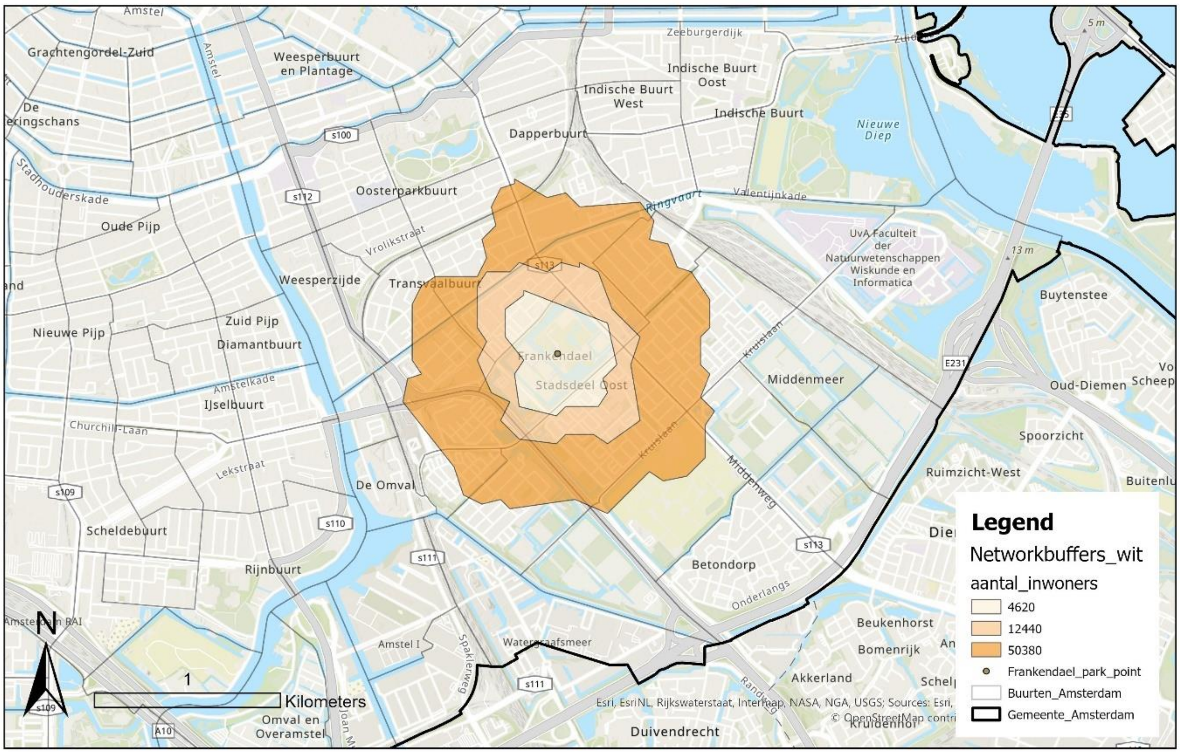

Figure 5: Accessibility Map

This map shows the areas with accessibility to the park (NbS) at 300m, 500m, and 1000m. The analysis found that approximately 4.620 inhabitants live within 300m, 12.440 inhabitants within 500m, and 50.380 inhabitants within 1000m of park Frankendael. This reflects the proximity-based access to the park and provides insight into how many residents may benefit from the NbS.

4.4.2.2. Demographic composition

This subsection presents demographic composition maps of the neighborhoods surrounding park Frankendael. The selected demographic indicators include age, income, ethnicity, and education level. These indicators provide contextual insight into the social characteristics of the surrounding area of the park. This analysis helps identify who is actually benefiting from the park's benefits. All the demographic variables were mapped using neighborhood-level data due to the limited availability of finer-scale demographic information.

4.4.2.2.1. Age maps

Age is an important demographic indicator for identifying vulnerable population groups like children and the elderly. Figure 6 and Figure 7 show the % children (0-15 years old) and % elderly (65+ years old) per neighborhood, respectively. Some of the neighborhoods are not colored due to data gaps in the neighborhood-level data.

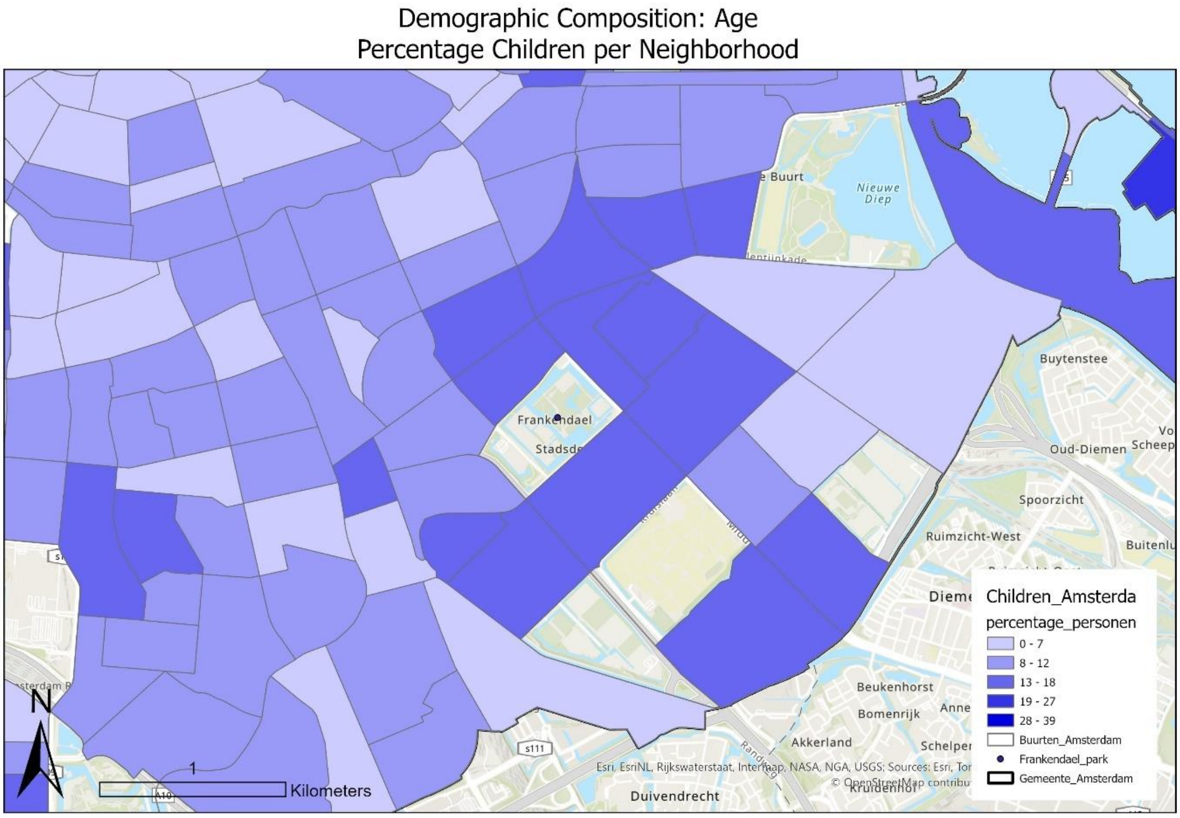

Figure 6: Age map: % children per neighborhood

The map reveals that directly north, south and east of park Frankendael, several neighborhoods are shaded medium purple, indicating a relatively higher proportion of children (13-18%). In contrast, neighborhoods in the north and west show a lower percentage of children (0-7% and 8-12%). While the neighborhoods with the highest percentages of children are not immediately surrounding the park, the data suggest that a moderate share of children live in the areas directly surrounding the park. This implies that this vulnerable group may still have access and could benefit from the park's benefits.

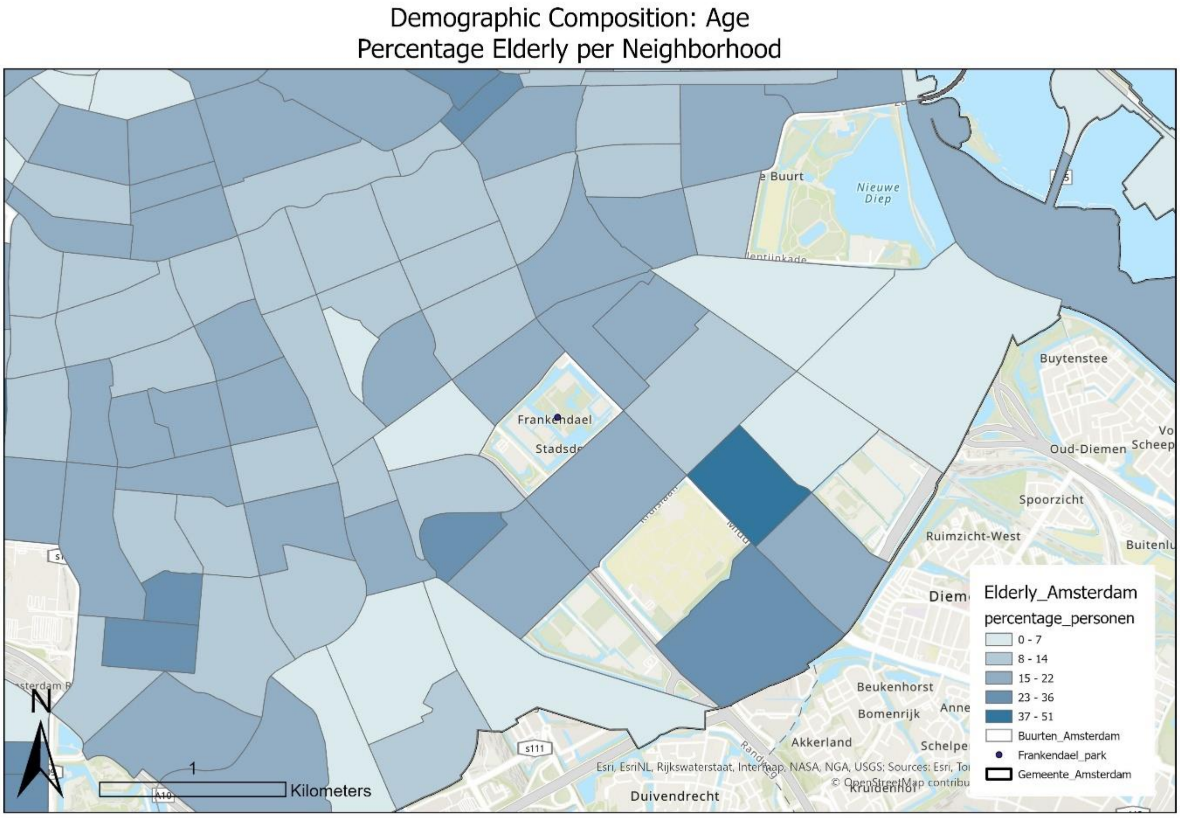

Figure 7: Age map: % elderly per neighborhood

Figure 7 shows that the neighborhoods directly surrounding park Frankendael are shaded medium blue, indicating a relatively high proportion of elderly (15-22%). One nearby neighborhood shows the highest percentage of elderly (37–51%), but it falls outside the 1000m network buffer. In the broader surrounding area, most neighborhoods fall within the 15–22% and 23–36% categories. Overall, this suggests that elderly residents are present in close proximity to the park and may benefit.

4.4.2.2.2. Income maps

Income is a relevant demographic indicator, as lower-income populations often have fewer opportunities and face greater environmental and social vulnerabilities. For example, during periods of extreme heat, lower-income households may lack access to cooling equipment such as air conditioning or fans, increasing their dependence on nearby green spaces like parks for thermal comfort. As such, access to Park Frankendael could provide meaningful benefits to this group. Figure 8 and Figure 9 present the average income per inhabitant and % low low-income households per neighborhood, respectively.

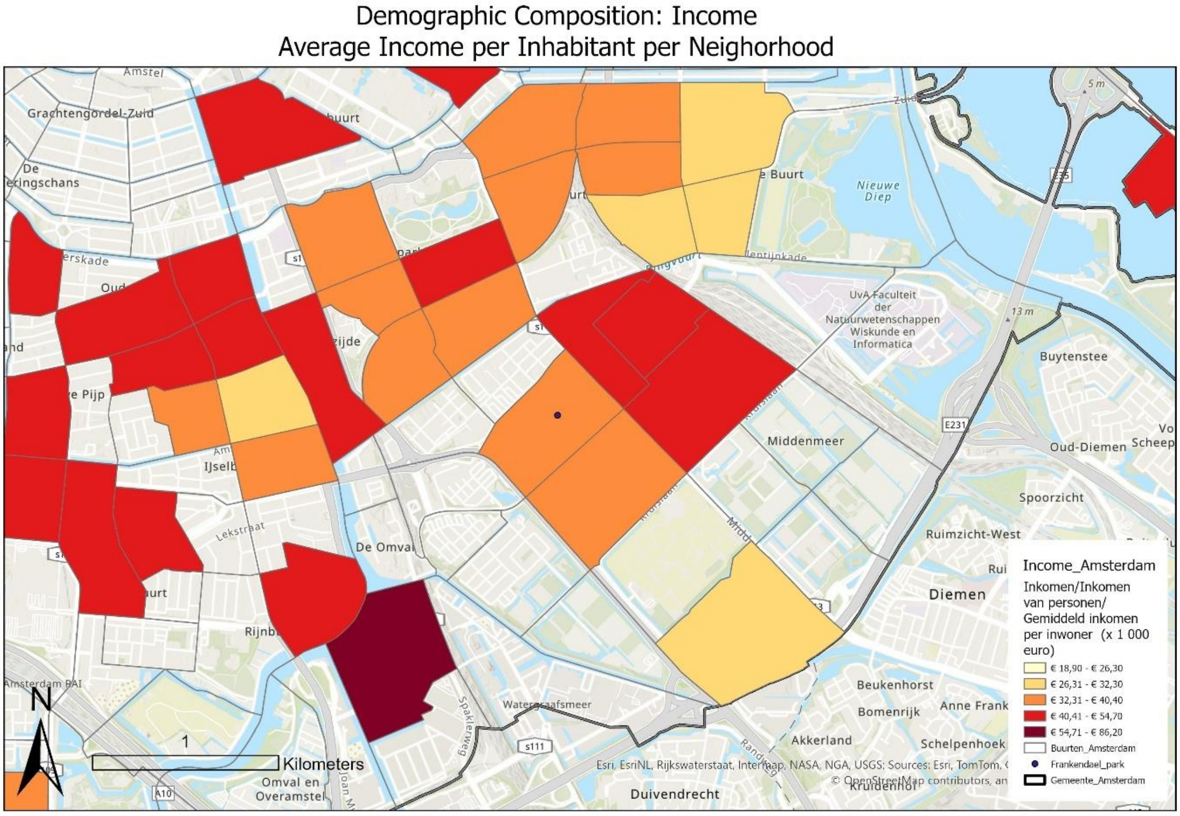

Figure 8: Income map: average income per inhabitant per neighborhood

This map contains a lot of data gaps, so conclusions should be drawn with caution, as not all neighborhoods are represented. However, for the neighborhoods with available data, most fall into the higher average income categories (€32,31k-€40,40k and €40,41k-€54,70k). This suggests that the population living near park Frankendael is, on average, relatively rich. Lower-income populations appear to be less concentrated near the park.

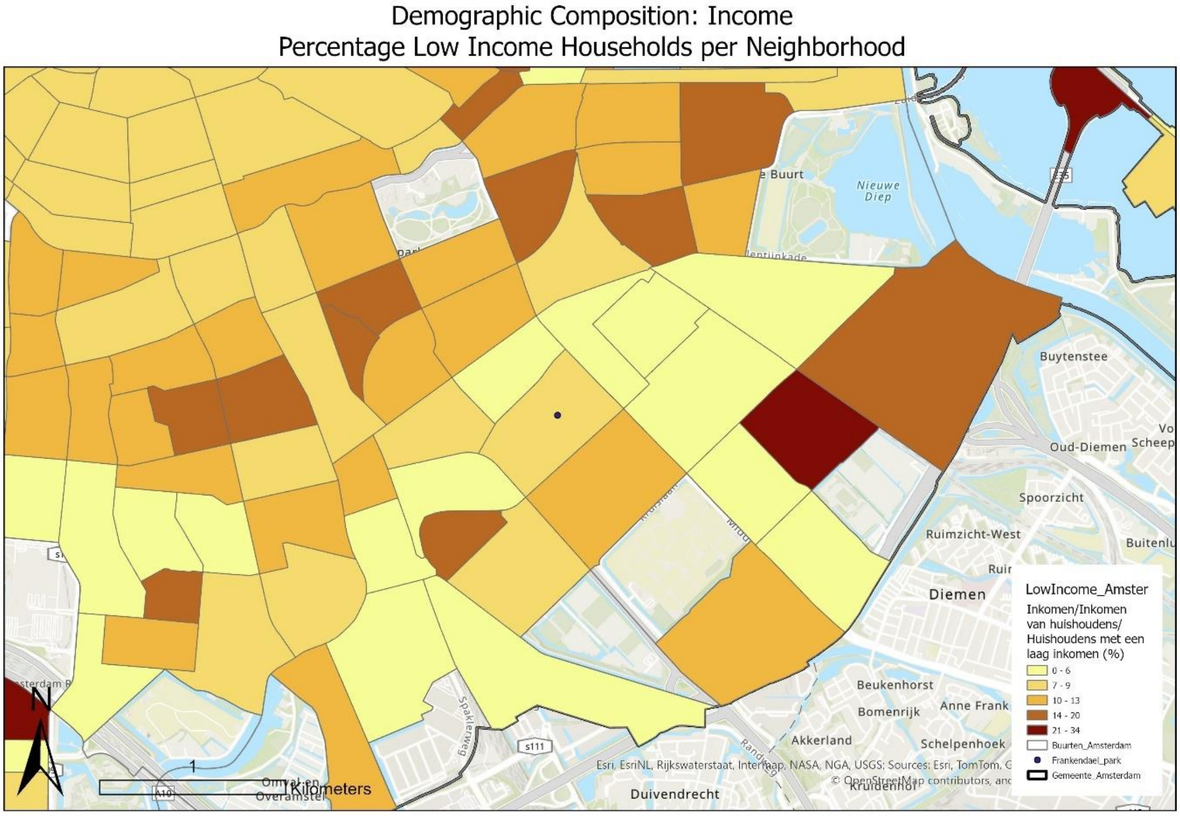

Figure 9: Income map: % low income households per neighborhood

This map reinforces the findings from Figure 8. Most neighborhoods directly surrounding Park Frankendael show a low percentage of low-income households (0–6% and 7–9%). Only one neighborhood with a relatively high percentage of low-income households (21–34%) is located nearby, but it falls outside the 1000m network buffer. Together, these maps suggest that lower-income residents do not live near the park and may not benefit equally from its benefits.

4.4.2.2.3. Ethnicity map

Ethnic and culturally diverse groups can be considered vulnerable populations due to structural inequalities that may affect their access to green space. These communities would especially benefit from the park Frankendaels' benefits. Figure 10 illustrates the % of the population with a non-European Origin per neighborhood.

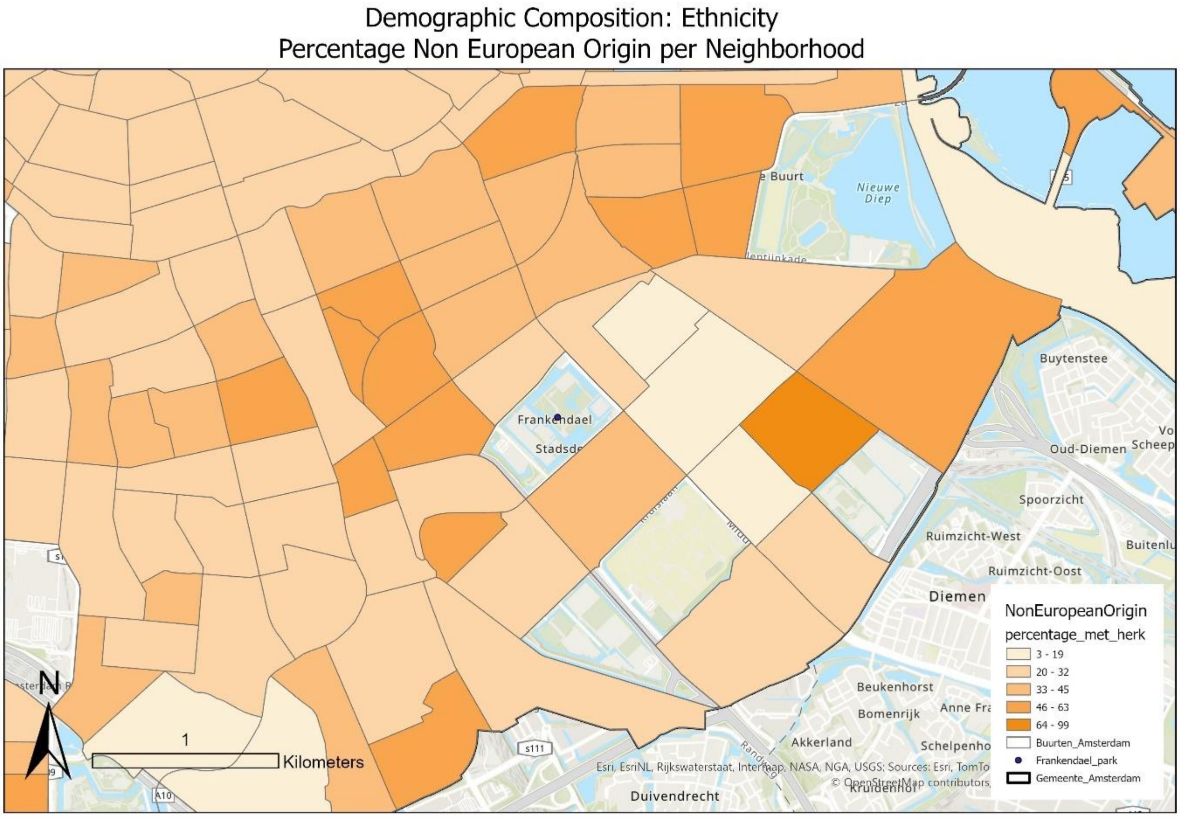

Figure 10: Ethnicity map: % non-European origin per neighborhood

The data reveals a wide variation across the area, ranging from 3% to 99%. Neighborhoods directly adjacent to park Frankendael generally fall within the lower to mid-range categories (3–19%, 20–32%, and 33–45%). One close-by neighborhood has the highest proportion (64-99%) of inhabitants with a non-European origin, but is, however, not within the 1000m network buffer. Overall, the results suggest that some residents of non-European origin live within an accessible distance of the park and may benefit from its services. However, the highest concentrations of these communities appear to be located farther from the park, indicating possible inequities in access.

4.4.2.2.4. Education level maps

Education level is a demographic indicator that can reflect underlying vulnerabilities. Individuals with a lower education level often face disadvantages related to, for example, health and income. Figures 11, 12 and 13 present the % of the population with low, medium, and high levels of education per neighborhood, respectively. However, it is important to note that the maps contain significant data gaps. As a result, conclusions should be interpreted with caution, since not all neighborhoods are represented in the analysis.

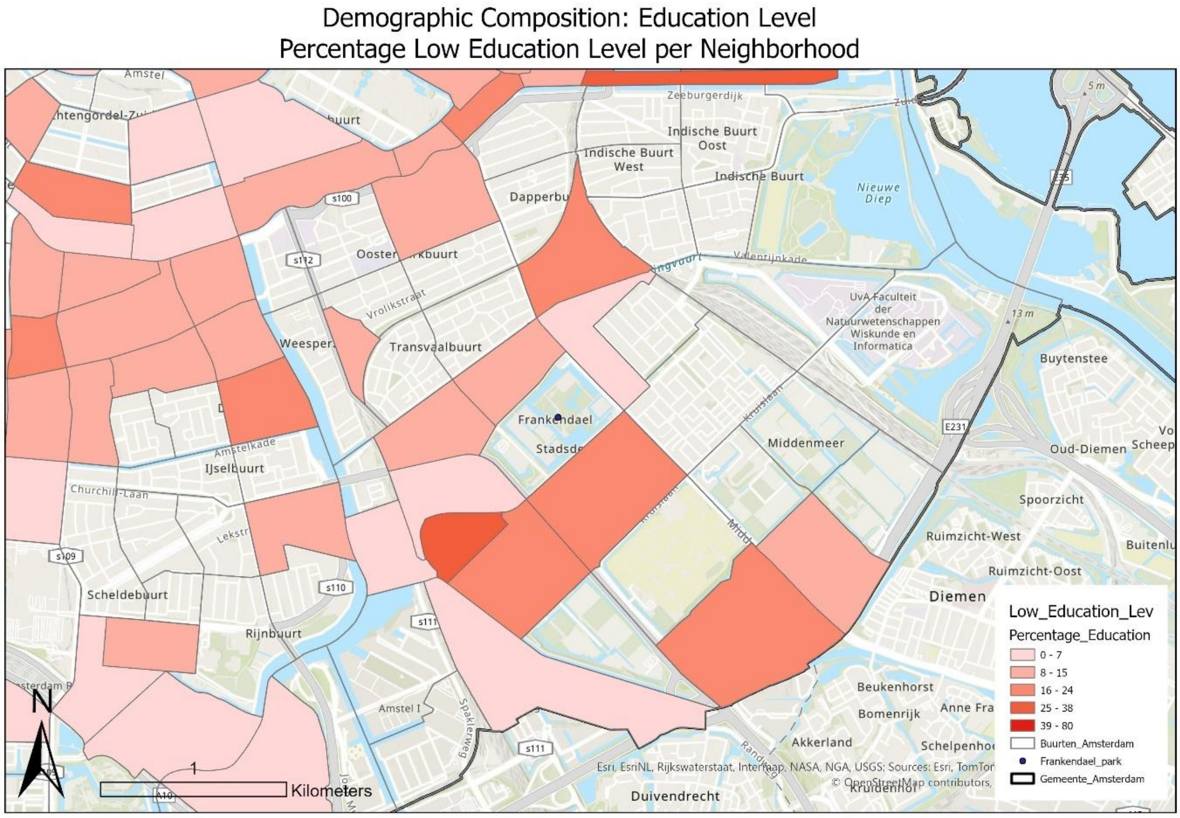

Figure 11: Education map: % low education level per neighborhood

Based on the available neighborhood data surrounding Park Frankendael, most neighborhoods show a low to medium percentage of residents with a low education level (0-7%, 8-15% and 16-24%). Overall, this pattern is consistent with the wider area where data is available. One nearby neighborhood shows the highest available proportion of residents with a low education level (25–38%, indicated in dark orange). This neighborhood falls partly within the 1000m network buffer, suggesting that some individuals with lower educational attainment live close enough to potentially benefit from the park.

Demographic Composition: Education Level
Percentage Medium Education Level per Neighborhood

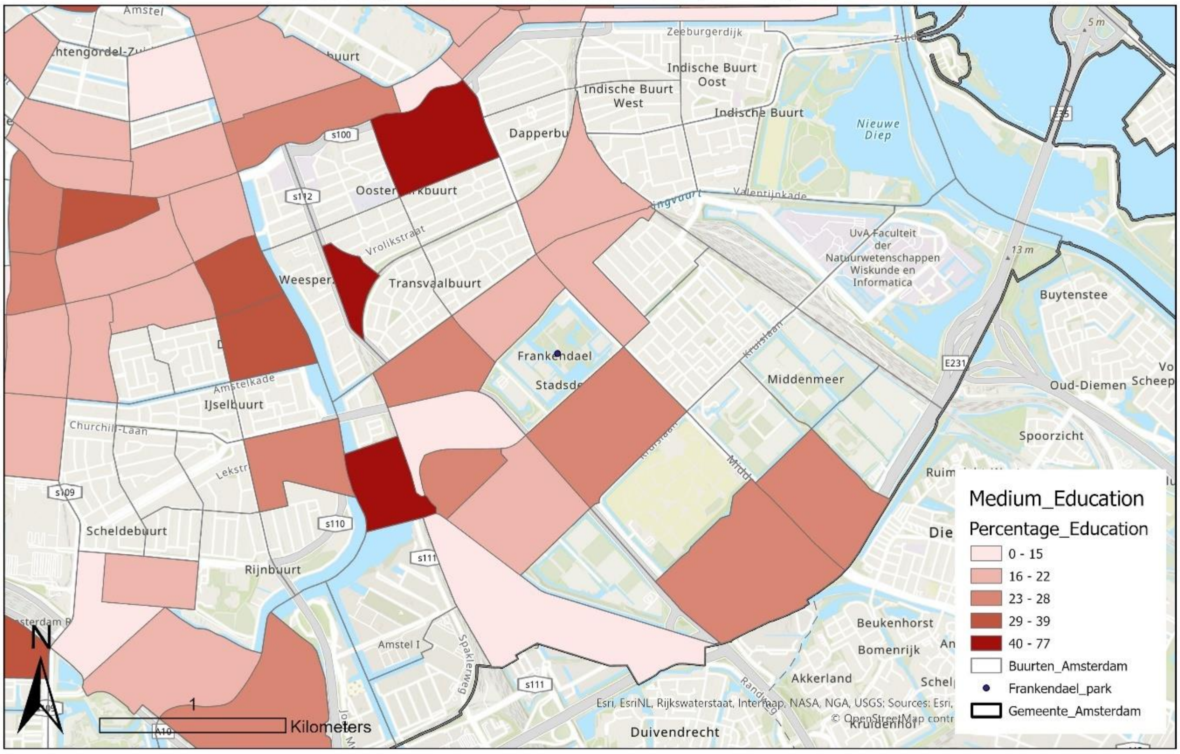

Figure 12: Education map: % medium education level per neighborhood

From the neighborhood data available, the areas surrounding the park have a low to medium percentage of inhabitants with a medium education level (16-22% and 23-28%). Three neighborhoods with the highest proportion in this category are located farther away from the park and fall outside the 1000m network buffer. This suggests that people with a medium education level live farther away from the park.

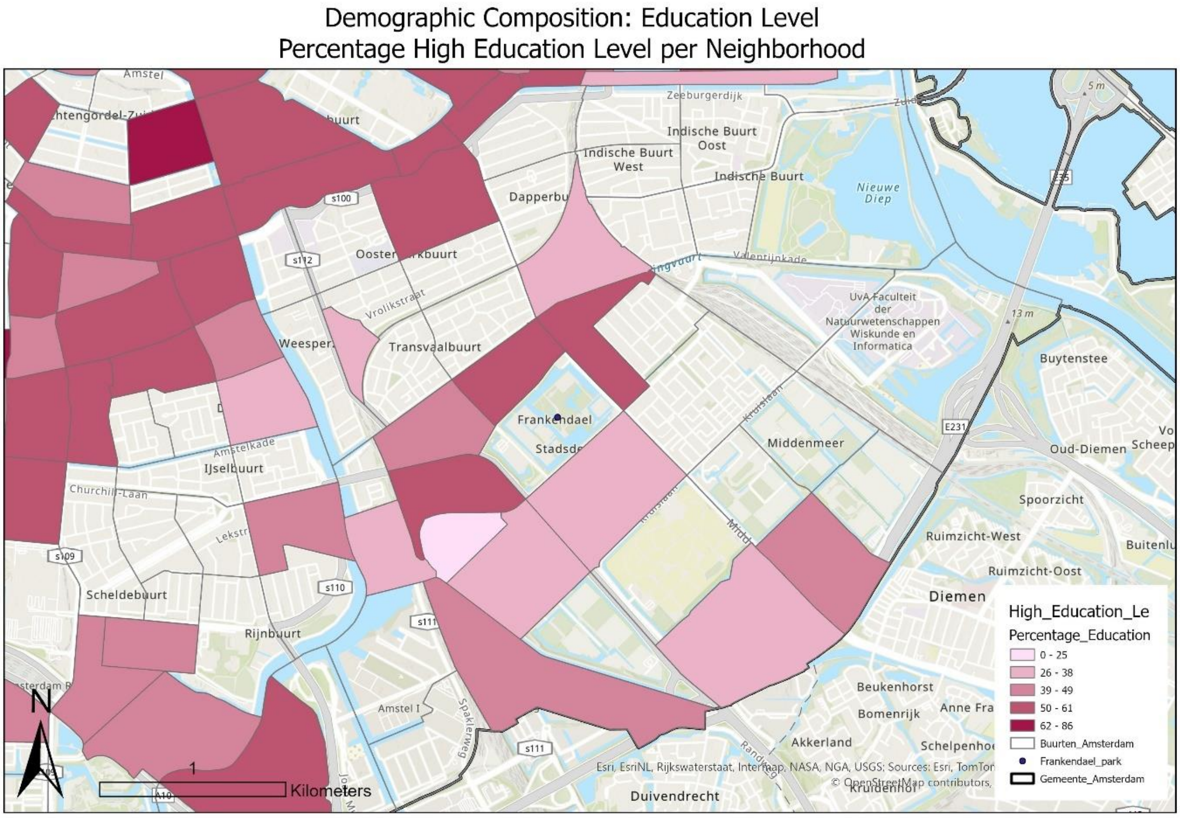

Figure 13: Education map: % high education level per neighborhood

This map shows that a lot of neighborhoods near the city center are shaded in darker red, indicating a higher share of residents with a high education level (50-61%). Directly surrounding the park, the neighborhood data available varies from medium to high share of people with a high education level (26-38%, 39-49%, and 50-61%). This suggests that individuals with higher educational levels are well represented in the park's immediate surroundings and may benefit from the park.

What can be concluded from all these education maps combined is that individuals with high education levels are more likely to reside close to park Frankendael, while those with low or medium education levels appear less represented in its immediate surroundings. This suggests that access to the park's benefits may not be evenly distributed across education levels.

4.4.2.3. Equitable distribution of blue-green space

This subsection examines the equitable distribution of access to park Frankendael by analysing the percentage of vulnerable groups living within walking distance of the park. This analysis combines accessibility and demographic data to assess whether access is fairly distributed. These vulnerable groups include children, elderly, and individuals of non-European origin. Population data with a 100m resolution grid is used to calculate the percentage of each group within the network buffers of 300m, 500m and 1000m. This helps determine the spatial proximity of these groups to the park and offers insight into whether access to its benefits is equitably distributed among different population groups. Figures 14, 15 and 16 present the percentage of children, elderly, and non-European origin individuals with access to the park, respectively.

Equity of Accces: Children
Percentage of Children within Network Buffers (300m, 500m, and 1000m) of Park Frankendael

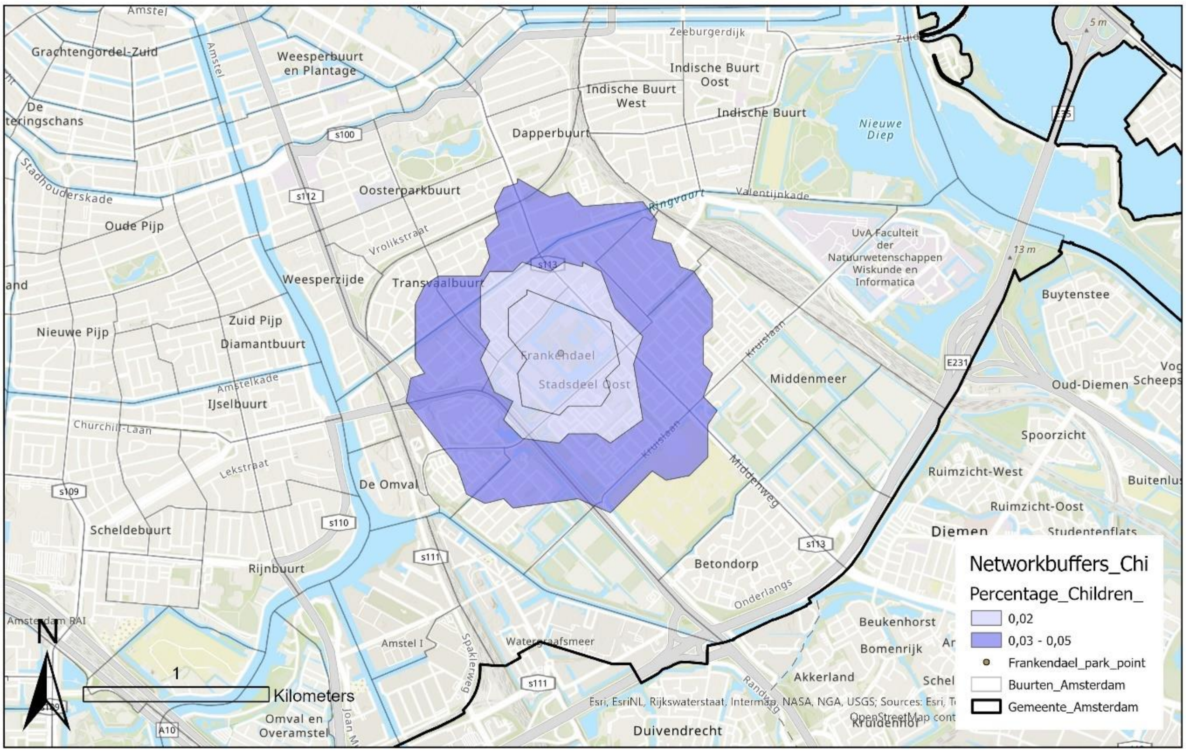

Figure 14: Equitable distribution map: % children within network buffers

This map shows the distribution of children who have access within the network buffers. It reveals that between 0,03-0,05% of Amsterdam's total population, represented by children, reside within a 1000m walking distance of the park. This suggests that a small share of the city's child population lives close enough to directly benefit from the park.

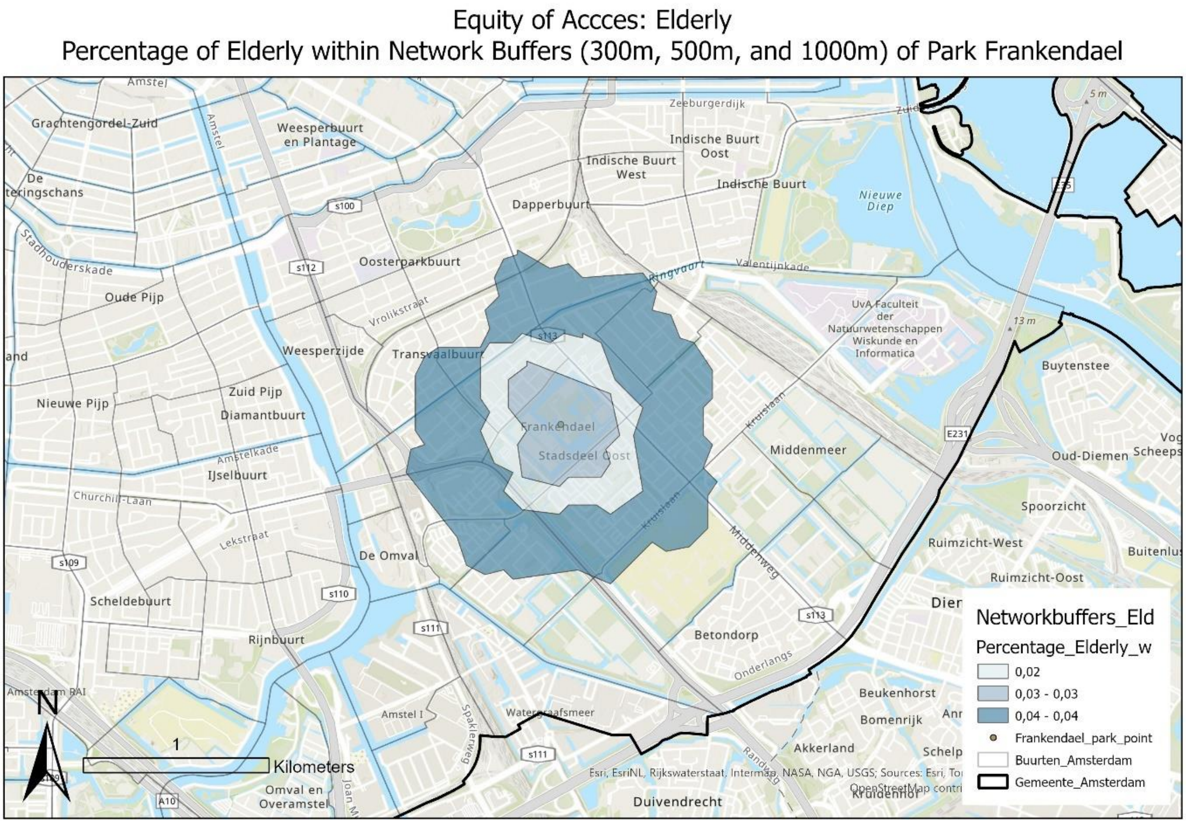

Figure 15: Equitable distribution map: % Elderly within network buffers

This map reveals the distribution of elderly who have access within the network buffers. It indicates that 0,04% of Amsterdam's total population, represented by elderly, live within a 1000m walking distance of the park. This is comparable to the percentage of children, indicating that both of these age-based vulnerable groups are similarly underrepresented in close proximity to the park.

Equity of Acccces: Non-European Origin
Percentage of Non-European Origin within Network Buffers (300m, 500m, and 1000m) of Park Frankendael

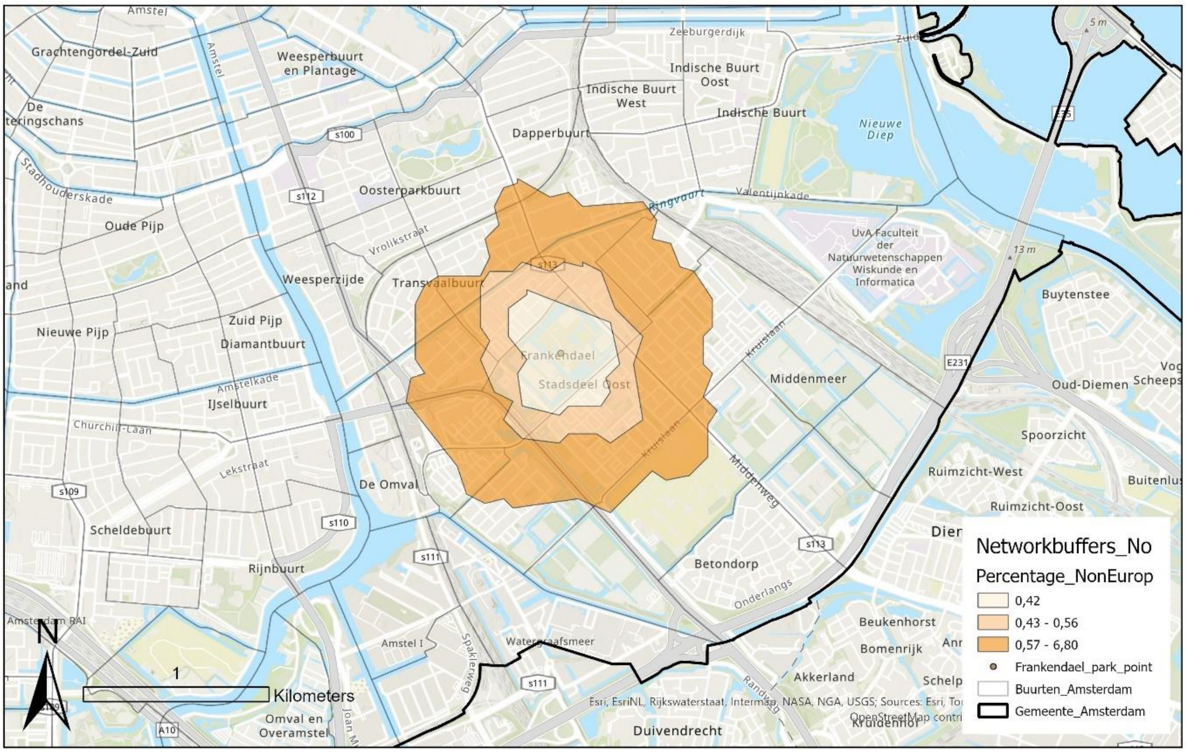

Figure 16: Equitable distribution map: % non-European origin within network buffers

Figure 16 illustrates the distribution of individuals with a non-European origin who have access within the network buffers. It indicates that 0,57-6,80% of Amsterdam's total population, represented by inhabitants with a non-European origin, live within 1000m of the park. This implies a relatively higher proportion of this demographic group has access to the park compared to children and the elderly. This outcome is expected, as the non-European origin category spans all age groups, children and elderly included.

Taken together, these maps highlight that some vulnerable groups may be underrepresented in areas with direct access to this NbS. This suggests that the benefits of park Frankendael may not be equitably distributed among all groups of the population.

The outcome of the case study revealed that park Frankendael may not deliver equitable NCP benefits to all vulnerable groups. The limitations of the data cannot substantiate a more definite conclusion (see section 5 for a more comprehensive discussion and section 6.3 for suggestions for further research)

5. Discussion

This section discusses the results of this thesis, its limitations, and implications for science and practice.

5.1. Interpretation of key results

5.1.1. Scoping relevant NCP categories and assessing contributions of urban NbS

To evaluate the applicability of the NCP framework to urban NbS, the full set of 18 NCP categories was reviewed and narrowed down to those most relevant to urban contexts. This scoping was informed by an analysis of urban environmental challenges and a conceptual linkage to each NCP category. Based on this assessment, 13 of the 18 categories were deemed relevant to urban environments. This process highlights the flexibility of the NCP framework, allowing it to be adapted based on local environmental and social contexts. For example, while NCP 5 (regulation of ocean acidification) may be relevant for coastal cities, it holds limited relevance for inland urban areas.

Table 3 presents an overview of how commonly implemented urban NbS contribute to the selected 13 NCP categories. Contributions were qualitatively assessed using a targeted literature review and an evaluation of each NbS type's primary function alongside its co-benefits. While the allocation of contributions (categorized as low, medium, or high) is not arbitrary, it remains context-dependent. For instance, the extent and scale of NbS implementation of green roofs can significantly influence their impact on, e.g., NCP 1: habitat creation and maintenance. Therefore, the contribution scores provided should be interpreted as general guidance rather than fixed values, acknowledging that local factors such as spatial distribution, design, and intensity of use may shift the relative importance of each NCP contribution.

5.1.2. Selecting NCP 16 and the corresponding indicators

To assess the contributions of urban NbS through the NCP framework, indicators were identified through a literature review. This resulted in a comprehensive list of indicators for each NCP category (see Appendix 8.1). For this thesis, the analysis focused specifically on NCP 16: physical and psychological experiences. This category includes physically and psychologically beneficial activities, healing, relaxation, recreation, leisure, and aesthetic enjoyment. These benefits align closely with cultural values and can be conceptually linked to the cultural ES category in the ES framework. NCP 16 was selected for further analysis for two main reasons. First, Table 3 indicates that NCP 16 has the highest overall contribution across all commonly used urban NbS types. Secondly, it captures cultural and relational dimensions that are underexplored in the previous ES-based assessment by Alvarado (2025) of the urban park Frankendael case study.

Unlike regulating or material NCPs, which emphasize ecological processes and provisioning functions, NCP 16 focuses on the lived human experience of nature. How people interact with, enjoy, and form attachments to urban green space. In dense cities, where many residents lack private gardens, urban parks become essential venues for these restorative, recreational, and aesthetic experiences.

NCP 16 offers a novel, people-centered lens for evaluating NbS benefits. While other NCPs and ES indicators tend to focus on biophysical values, such as how much CO_2 is captured or how much stormwater is retained, NCP 16 highlights who can actually access and benefit from the NbS, and how these benefits are distributed among social groups. By linking cultural values, physical and psychological benefits to questions of accessibility and equity, NCP 16 reveals social and justice-oriented dimensions of NbS that traditional assessments, such as the ES framework, may overlook. This makes it especially relevant for urban planning that aims to be both sustainable and inclusive.

From the broader list of NCP 16 indicators, three were selected for spatial analysis: accessibility, demographic composition, and equitable distribution of blue-green space. These were chosen based on their relevance to the urban context, the availability of reliable data, their suitability for spatial analysis, and their linkage to NCP 16. Together, they formed the basis for applying NCP 16 to the case study of Frankendael Park.

5.1.3. Application of indicators: spatial analysis of park Frankendael

In this thesis, three indicators were applied to a spatial analysis of park Frankendael: accessibility, demographic composition, and equity distribution of blue-green space.

5.1.3.1. Accessibility

Accessibility was analysed using network buffers of 300, 500 and 1000 meters, assuming walking as the primary mode of transport. This approach offered a useful first approximation of physical proximity to the park, which is a common proxy for access in urban studies. The results showed that a substantial number of residents live within walking distance and could potentially benefit from the park's benefits. The representation of access in this may be limited, but it can show an indication.

5.1.3.2. Demographic composition

The demographic composition around the park was examined using neighborhood-level data on age (children and elderly), income, ethnicity (non-European origin), and education level. These groups were chosen because they are often more vulnerable to environmental risks and may have fewer resources, and could therefore really benefit from the park.

The maps showed that while children and elderly residents are relatively well-represented near the park, lower-income households and those with a lower educational level appeared to be less concentrated in the immediate surroundings of the park. For the residents with a non-European origin, the results show that they are represented in nearby neighborhoods, but some higher percentage neighborhoods are located farther away from the park. This could indicate a potential inequity in access across low-income, low education level and non-European origin residents.

5.1.3.3. Equitable distribution of blue-green space

The equitable distribution of blue-green space indicator shows the equitable distribution of the park. It combined accessibility and demographic factors to examine how equal the access is to the park for different vulnerable groups. The proportion of vulnerable groups within each network buffer was calculated. The maps showed that children and elderly were underrepresented in the network buffers of the park. Residents with a non-European background were slightly better represented but still not proportionally.

5.1.4. Comparing ES assessment vs NCP 16 assessment

The ES assessment by Alvarado (2025) provided a broad evaluation of park Frankendael's benefits (see Table 6), capturing both regulating ES, such as air quality, climate, water and temperature regulation, and cultural ES, including municipal income from community gardens, aesthetic value, leisure, spiritual enrichment, education, and mobility. Several of these benefits were quantified and, in some cases, linked to monetary values using the i-Tree Eco tool and other ad-hoc methods. The i-Tree Eco tool is well-suited for quantifying tree-related regulating services (e.g., carbon sequestration or air pollution removal). However, it is limited in scope as it does not account for other forms of vegetation, soils, or water bodies. In urban parks with fewer trees, this could lead to an underestimation of total benefits. Moreover, the i-Tree Eco tool focuses on biophysical indicators and overlooks cultural services. For this reason, cultural ES in the Frankendael case study had to be addressed through supplementary methods (e.g. surveys, interviews, and literature values). While this ES assessment highlights a range of benefits the park has to offer, it does not account for who benefits from them, nor does it explicitly consider equity.

In contrast, the NCP-based assessment in this thesis specifically focused on NCP 16: physical and psychological experiences, with an emphasis on accessibility and equitable distribution of these benefits across different demographic groups. The GIS-based spatial analysis identified which populations live within walking distance of the park and revealed underrepresentation of certain vulnerable groups, including children, elderly, residents of non-European origin, and low-income households. Limitations of the analysis are discussed in 5.2.

By comparing these findings with Alvarado's ES assessment, the understanding of park Frankendael's benefits becomes more nuanced. The ES assessment quantified regulating services and, through qualitative methods, highlighted cultural values, but did not address who could access these benefits. The NCP 16 analysis adds this perspective, showing that certain groups are underrepresented and therefore less able to benefit. It shows who actually benefits and who is excluded. Integrating both approaches links biophysical outputs with their social distribution, providing a fuller picture of how the park functions within the city. In this way, the ES assessment highlights the range and magnitude of services, while NCP adds a people-oriented lens that exposes inequities and contributes insights into environmental justice, urban equity, and inclusive NbS planning.

5.2. Assumptions and limitations

This thesis has several assumptions and limitations that will be discussed in this section.

5.2.1. Accessibility analysis

The spatial accessibility analysis used proximity to the NbS as a proxy for access, defining accessibility through walking distance buffers (300, 500, and 1000 meters). This choice was based on the indicators identified in the literature, data availability, and providing a replicable method. However, this is a simplification and is not the only way that access can be defined. Other factors were not accounted for, such as access via public transport, cycling, or car, as well as mobility barriers for people with disabilities (e.g., sidewalk width, slope), the actual use, perceptions of safety, comfort or other social barriers. These factors would provide a more accurate picture of who truly has access to the park. Proximity alone does not equal access or use. So while proximity measures provide replicable results, they risk overlooking how social, cultural, or other factors shape the actual access and use.

Additionally, there were limitations in creating the road network datasets due to disconnected pathways and missing traffic restrictions (e.g. one way streets or barriers), which may have affected the accuracy of the calculated network buffers for the analysis.

5.2.2. Demographic composition

All demographic variables were assessed using neighborhood-level data, as finer-resolution demographic information was not accessible for all factors. Although this doesn't necessarily mean that the results aren't useful, as they provide a broad overview of where vulnerable groups live. However, caution is needed when interpreting these results due to data gaps. Some demographic data were missing or incomplete, particularly for income and education. This makes the results less reliable. Moreover, the use of broad categories such as 'non-European origin' may also oversimplify complex socio-cultural identities, potentially obscuring nuanced inequalities. Lastly, using neighborhood-level data ensured citywide coverage but came at the cost of masking fine-scale inequalities that may exist within neighborhoods.

5.2.3. Equitable distribution of blue-green space

The analysis of the equitable distribution of blue-green space was limited by the lack of fine-scale socioeconomic data. Specifically, income and education data were not accessible at the 100-meter resolution grid level. This level of detail is essential for accurately calculating the proportion of different income and education groups within the defined network buffers. Relying on aggregated neighborhood-level data could therefore misrepresent local inequities and may lead to under- or overestimation of disparities in access. Therefore, only children, elderly, and residents with a non-European origin could be analysed as there was 100-meter grid data available for those. Furthermore, consistent with the accessibility analysis (see section 5.2.1), this assessment assumes that spatial proximity equates to access, which is an oversimplification.

5.2.4. Time and resource intensity

One overarching limitation concerns the time-consuming nature of the NCP assessment process. While ES assessments already require substantial data collection and analysis, applying the NCP framework with its emphasis on equity and social dimensions adds an additional layer of complexity. This increases the workload for practitioners and researchers. However, this effort is justified when the goal is to ensure more equitable and socially just implementation of NbS. Moreover, once policymakers have collected data, it can be reused for multiple analyses. Additionally, the rise of AI could help reduce the analytical burden.

5.2.5. Qualitative and quantitative research

This study relied primarily on literature review and quantitative spatial analysis using network buffers and neighborhood-level census data. The literature review provided a crucial foundation, identified relevant indicators, and guided methodological choices. However, a literature review comes with limitations, as the selection process may have excluded valuable studies due to predefined criteria. Given the scope and aim of this research, the risk is considered minor but should be acknowledged.

The use of quantitative methods allowed for broader area coverage and replicable, objective measurement of accessibility, demographic composition, and equity distribution. Additionally, the spatial analysis produced visual maps, offering an effective tool to communicate findings to policymakers in a clear way. Yet, it comes with limitations, such as reduced ability to capture individual experiences, subjective perceptions of access, or qualitative cultural values that may influence park use. Additionally, key modeling decisions, such as the use of 300, 500, and 1000 meter buffer distances and reliance on neighborhood-level demographic data, while necessary for replicability, simplify complex realities. The buffer distances are used as a proxy for access, which can be identified in multiple ways and may not reflect the lived mobility constraints of different demographic groups. The use of neighborhood-level data ensures coverage but risks overlooking fine-scale inequities. These simplifications are important to acknowledge as they shape how the results are interpreted.

5.3. Implications for urban planning and practice

The findings of this thesis carry implications for urban planners, policymakers, and practitioners working with NbS. By incorporating a relational and equity-focused lens through the NCP framework, this analysis sheds light on who benefits from urban NbS, an aspect often overlooked in traditional, commonly used ES assessments.

The NCP 16 spatial analysis of park Frankendael revealed an underrepresentation of vulnerable groups, including children, elderly, residents of non-European origin, and low-income households. This result aligns with broader debates, such as gentrification. While the introduction of NbS can improve environmental quality and neighborhood appeal, it may also contribute to rising housing costs. This process attracts wealthier residents and can indirectly displace vulnerable (e.g., lower-income) communities. This unintended consequence creates a paradox in which the very groups that could benefit most from the NbS may be pushed out due to market-driven dynamics. These patterns raise questions about whether the benefits of NCP 16 are being captured disproportionately by more privileged groups.

Furthermore, these same dynamics are also tied to the ongoing debate around green justice. This is the principle that all people, regardless of race, income, or social status, have equal access to a healthy environment and are not disproportionately burdened by environmental harms. The underrepresentation of vulnerable groups around park Frankendael suggests that this principle may not be fully realized in this case. However, the analysis did not account for other surrounding green spaces in the area.

These debates also point to wider urban justice concerns, such as distributional justice (who benefits), procedural justice (who is involved in decision-making), and recognitional justice (whose cultural and social needs are acknowledged). Traditional ES assessments tend to focus on the quantity and type of services provided by nature, but often fall short of identifying who actually benefits from them. The NCP framework adds this critical social dimension and addresses distributional justice by emphasizing equity, cultural context, and inclusion. By bridging ecological and social research, the NCP framework offers a more nuanced equity lens than ES approaches alone. Applying this perspective helps ensure that equity and inclusion remain central to NbS evaluation, planning, and implementation, ultimately enabling interventions that are not only ecologically effective but also socially just.

This thesis provides a reproducible NCP 16 indicator set that can be used for NbS equity research and planning and implementation phases of NbS. It helps identify which demographic groups are situated near the intervention, allowing planners to assess whether certain populations are systematically excluded. This information can guide more equitable decision-making by informing which stakeholders to engage and ensuring that diverse cultural perspectives and lived experiences are taken into account. Adopting this more bottom-up and inclusive planning process can strengthen the legitimacy and long-term success of NbS. When communities are genuinely involved (addressing procedural justice) and feel their needs are reflected in the design and purpose of the NbS (addressing recognitional justice), they are more likely to support, maintain, and benefit from it. In this way, the NCP framework not only enhances scientific assessments but also contributes to more just and inclusive urban development.

6. Conclusion

Urban resilience is important to cities facing pressures of climate change. A way to enhance urban resilience is through NbS. This thesis addressed the current gap in ES evaluations of NbS in urban environments. To do so, it explored the potential of the NCP framework, which offers a broader and more inclusive perspective. NCP is applicable to urban areas and has added value, bridging this gap, but further research is needed.

The conclusion begins by outlining the scientific contribution and novelty of the study. It then answers the research questions one by one, reflecting on method choices and limitations, and ends with recommendations for future research.

6.1. Scientific contribution and novelty

This research explored the applicability of the NCP framework to assess NbS in urban settings by applying identified NCP indicators to park Frankendael, Amsterdam. The NCP framework has so far seen limited use in the urban context, and this study aimed to explore its added value compared to the more commonly used ES framework.

This thesis started with a conceptual comparison of the NCP and ES frameworks. This comparison highlighted that the ES framework often overlooks cultural, relational, and context-specific values and views, while these elements are especially important in diverse urban settings with residents from different cultures and perspectives. In contrast, the NCP framework has the potential to bridge this gap by offering a more holistic view that includes these dimensions.

For this purpose, the study first identified which of the 18 NCP categories are relevant to urban environments and how those contribute to different frequently used urban NbS. Subsequently, indicators for assessing these NCP categories were compiled from the literature. Finally, a selection of NCP indicators related to NCP 16 was applied to a spatial analysis of the case study.

This thesis contributes to the emerging body of work applying the NCP framework in practical contexts and demonstrates its potential to provide deeper insights into the social and cultural dimensions of NbS in cities, which is important for the successful implementation of NbS.

6.2. Answering the research questions

The main research question of this thesis is as follows: *"How can the Nature's Contributions to People framework be applied to evaluate the benefits of nature-based solutions in urban environments?"*

To answer this main research question, four different sub-questions were explored:

SQ1: "What existing frameworks are used to evaluate the benefits of NbS and how does the most prominent one compare with NCP?"
The literature review showed that the ES framework is the most widely used approach for evaluating the benefits of NbS in urban environments. A comparative analysis between the ES framework and the NCP framework revealed that, while ES is well-established, it tends to underrepresent relational values, cultural aspects, and equity considerations. This confirmed the potential of NCP to address these shortcomings of the ES framework.

The use of a literature review was considered appropriate given the conceptual nature of this question and the need to map existing academic discourse. However, the analysis could have been further strengthened by incorporating expert interviews or stakeholder perspectives, which might have provided more practice-based insights and addressed any blind spots in the literature.

SQ2: "Which NCP categories are most relevant to urban environments, and how do NbS contribute to these categories?"
To answer SQ2, key urban environmental challenges were first identified through a targeted literature review and used to narrow down the original 18 NCP categories to 13 that are most relevant to urban environments. This demonstrates that the NCP framework is adaptable to urban contexts. A scoring matrix was then developed to assess how commonly used urban NbS contribute to these 13 NCP categories. The analysis shows that the contribution of NbS to NCP categories is highly dependent on the design and local context of the NbS. NCP 16 (physical and psychological experiences) emerged as particularly relevant, as it consistently scored high across different types of NbS.

The chosen method, based on a literature review and qualitative scoring, was effective for this broad exploration but remains partly subjective. Including expert interviews or workshops could have added further nuance in determining relevant NCPs and assessing the contribution of NbS.

SQ3: "What indicators or proxies can be used to assess NCP in urban NbS?"
A targeted literature review was conducted to address SQ3. The literature review showed that multiple indicators exist to assess NCP in urban NbS. However, this thesis focused on NCP 16, as it showed the most promise in the developed scoring table and its potential to address relational, cultural, and context-specific values. Three NCP 16 indicators were selected (accessibility, demographic composition, and equity distribution) to be tested in the spatial analysis conducted in SQ4.

This method allowed for a structured overview of indicators, but relying only on literature risks missing local or practice-based indicators. Choosing NCP 16 narrowed the focus and ensured feasibility, though it limited the scope. A mixed-method approach or expanding to other NCP categories could strengthen future research.

SQ4: "How can the NCP framework be applied to a case study of an urban NbS and what insights does this provide?"
The NCP 16 indicators selected in SQ3 were tested in a spatial analysis of park Frankendael. The analysis demonstrated that the NCP framework is operationalizable in urban case studies. It provided added value by revealing spatial inequities, highlighting who benefits from NbS and who may be excluded, something not captured in the previous ES assessment by Alvarado (2025). This shows that the NCP 16 analysis can complement ES by integrating equity and relational values. The thesis delivered a reproducible NCP 16 indicator set and method to visually represent the findings, which adds to NbS equity research. However, the reliance on quantitative spatial data may overlook subjective experiences, suggesting future research could combine spatial and qualitative methods for a fuller understanding.

6.3. Recommendations for future research

Based on the findings and limitations of this thesis, multiple recommendations can be made for future research to further advance the use of the NCP framework for urban NbS.

Firstly, the scoping of the NCP categories could be improved by stakeholder input. The selection of relevant NCP categories was based on urban environmental challenges identified in the literature. Future research could strengthen this scoping process by including interviews or workshops with local experts and practitioners, such as municipal planners or community representatives. This would help validate and refine the selection of NCPs based on local knowledge and practical relevance.

To move beyond assumptions of proximity equating to access, future studies should integrate qualitative methods such as user surveys, interviews, or site observations to validate the accessibility assumptions. These could assess actual use patterns, transportation modes, and perceived barriers to access. Additionally, studies could consider multimodal access indicators, such as proximity to public transport stops, cycling infrastructure, car parking availability, and connectivity to urban centers.

Future research should aim to find more categories of demographic data (e.g., at the 100-meter grid level) to allow for even more detailed equitable distribution maps of other vulnerable groups. Moreover, demographic categorizations should be refined to avoid overgeneralizations, for example, by distinguishing between different ethnicities.

This thesis focused on NCP 16, but future research could compare and apply other NCP categories, such as NCP 17, or regulating NCPs, to provide a more comprehensive understanding of NbS contributions in urban areas. Additionally, the method could be applied to multiple parks within Amsterdam or other cities. This would enable a comparative analysis and reveal broader patterns of inequity or access disparities across different urban settings. Furthermore, the method could be applied to other urban NbS types, such as community gardens.

Furthermore, research could examine housing prices, gentrification indicators, and the ratio of owner-occupied vs. rental housing in neighborhoods surrounding the park. This could help understand how NbS interventions may impact housing markets and displacement risks in areas with vulnerable populations. Additionally, future studies could explore access to private green spaces, such as gardens and courtyards. Individuals with access to private outdoor space may have different dependencies or patterns of park use, influencing the overall equity assessment of public park use.

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8. Appendix

8.1. List of identified indicators to assess NCP in urban NbS

Table 7 presents the full list of identified indicators to assess NCP in urban NbS

Table 7: Identified indicators per NCP category

NCP category	Indicator/proxies	Sources
NCP 1: Habitat creation and maintenance	Public green space distribution (total surface or per capita)	(Connop et al., 2020; EC, 2021)
	Structural and functional connectivity of green and blue spaces (measured by spatial connectivity, habitat continuity, and ecological network analysis (e.g., least-cost path, mesh density, conservation planning tools))	(Connop et al., 2020) (EC, 2021) (Zhou et al., 2023) (Ommer et al., 2022)
	Area (m2)/ size (ha)	(Kato-Huerta & Geneletti, 2022) (Watkin et al., 2019)
	Normalised Difference Vegetation Index (NDVI)	(Kato-Huerta & Geneletti, 2022) (Kothencz & Blaschke, 2017)
	Species richness (# of species in an area) and diversity (species distribution), shannon diversity index	(Kato-Huerta & Geneletti, 2022) (Kabisch et al., 2016) (Jegatheesan et al., 2022) (Li et al., 2025) (Tudorie et al., 2020) (EC, 2021) (Köhler & Ksiazek-Mikenas, 2018) (Ommer et al., 2022)
	Fragmention of habitat (Ecological fragmentation index)	(Kato-Huerta & Geneletti, 2022) (Köhler & Ksiazek-Mikenas, 2018) (EC, 2021)
	Vegetation cover (%)	(EC, 2021) (Kabisch et al., 2016) (Kothencz & Blaschke, 2017) (Li et al., 2025)
	Total leaf area (m2)	(EC, 2021)
	Biomass (total mass of plants, animals or microbes in an area, weight per unit area or volume)	(Li et al., 2025)
	Habitat heterogeneity, species suitability	(Tudorie et al., 2020)
	Abundance and distribution of selected species	(Ommer et al., 2022)
NCP 2: Pollination and dispersal of seeds and other propagules	Pollinator habitat (Floral availability and nesting suitability (ESTIMAP Index (score))	(Langemeyer et al., 2019)
	Abundance and diversity of pollinators	(Veerkamp et al., 2021) (EC, 2021)
	Impervious land cover	(La Rosa et al., 2015)
	Amount of pollutants in or removed from soil	(Veerkamp et al., 2021)
NCP 3: Regulation of air quality	Decrease in air pollution	(Veerkamp et al., 2021) (Kabisch et al., 2016) (Van Oorschot et al., 2021)
	Concentrations of SO2, PM10, O3, NO2, CO, PM2.5, etc.	(Dong et al., 2025) (Jegatheesan et al., 2022) (Van Oorschot et al., 2021) (Tudorie et al., 2020) (EC, 2021) (Ommer et al., 2022)
	Potential/ actual tree canopy cover (%), Tree height (m), (total leaf area (m2)	(Kato-Huerta & Geneletti, 2022) (EC, 2021)
	Respiratory disease	(EC, 2021) (Kabisch et al., 2016)
	Road congestion level, road density, carbon emissions from vehicle traffic	(Dong et al., 2025) (EC, 2021)
	t of carbon stored and carbon emission by vegetation	(Kabisch et al., 2016) (Watkin et al., 2019)
	Ambient pollen concentration	(EC, 2021) (Ommer et al,, 2022)
	Mortality due to poor air quality (#/year)	(EC, 2021)
NCP 4: Regulation of climate	NbS area (area in relation to population, area per captia). Area (m2), Size (ha)	(Connop et al., 2020) (Kato-Huerta & Geneletti, 2022) (EC, 2021)
	vulnerability to heat: populaiton density (hab/km2), elderly population density(hab/km2)	(Camacho-Caballero et al., 2024)
	tree shade for local heat change (measured by temp (C or K) per spatial unit (m2), depend on tree species(size, shape, leaf type, etc))	(Connop et al., 2020) (EC, 2021) (Watkin et al., 2019)
	Potential/ actual tree canopy cover (%), Tree height (m)	(Kato-Huerta & Geneletti, 2022)
	Heat related mortality, decline premature death during heat waves	(Kabisch et al., 2016) (EC, 2021) (Nature4Cities, 2017)
	Temperature regulation: land surface temperature (depend on tree coverage and Leaf Area Index (LAI), air temperature, PET, UTCI, heat exposure	(Dong et al., 2025) (EC, 2021) (Ommer et al., 2022) (Van Oorschot et al., 2021)

	Heat stress reduction: UHI intensity, heat vulnerability	(Dong et al., 2025) (Van Oorschot et al., 2021) (Jegatheesan et al., 2022) (EC, 2021) (Veerkamp et al., 2021)
	Total amount/yearly carbon sequestration and stored in vegetation , Carbon stock of each vegetation unit, tree density	(Tudorie et al., 2020) (Mexia et al., 2017) (Ommer et al., 2022)
	Reduction of concrete and asphalt areas, Impervious land cover	(Watkin et al., 2019) (La Rosa et al., 2015)
	total vegetation cover (%), area of vegetated surfaces, total leaf area (m2)	(EC, 2021) (Kothencz & Blaschke, 2017)
NCP 6: Regulation of freshwater quantity, location and timing	Runoff coefficient	(Langemeyer et al., 2019) (Tudorie et al., 2020)
	Stormwater runoff (mm)	(Van Oorschot et al., 2021)
	Flood peak reduction	(Tudorie et al., 2020):
	Irrigation cost (cost for all sources of irrigation for water storing NbS)	(Watkin et al., 2019)
	Infiltration, roundwater recharge	(Watkin et al., 2019)
	Rate of evapotranspiration	(EC, 2021)
	Rainfall interception of NbS (mm/h)	(EC, 2021)
NCP 7: Regulation of freshwater and coastal water quality	Water quality: proxies nitrate, phosphor, and sediments	(La Rosa et al., 2015) (Ommer et al, 2022)
	Sediment and nutrient removal from water	(Veerkamp et al., 2021) (Watkin et al., 2019)
	(reduced) mortality rate of aquatic animals as an indication of (environmental) health	(Veerkamp et al., 2021)
	Water purification - calculated with InVEST software	(Mexia et al., 2017)
NCP 8: Formation, protection and decontamination of soils and sediments	Organic matter (%), nutrients (wt%) and water holding capacity	(Kato-Huerta & Geneletti, 2022)
	Noise pollution (reduction of noise pollution due to the absorption of sound waves through soil and plants)	(Dong et al., 2025) (Watkin et al., 2019)
	Amount of pollutants in or removed from soil	(Veerkamp et al., 2021)
	Polluted soils (ha), equivalent used soil (m3)	(EC, 2021)
	Erosion prevention - calculated with InVEST software	(Mexia et al., 2017)
	Carbon storage and sequestration by soil: InVEST provides estimates for different land uses/covers	(Ommer et al., 2022)
	Bulk density (g/cm3),	(Kato-Huerta & Geneletti, 2022) (Ommer et al., 2022)
NCP 9: Regulation of hazards and extreme events	NbS area (area in relation to population, area per captia). Area (m2), Size (ha)	(Connop et al., 2020) (Kato-Huerta & Geneletti, 2022) (EC, 2021)
	Vulnerability to heat: populaiton density (hab/km2), elderly population density(hab/km2)	(Camacho-Caballero et al., 2024)
	% reduction in flood risk	(Kabisch et al., 2016)
	Heat-related mortality, decline in premature death during heat waves	(Kabisch et al., 2016) (EC, 2021) (Nature4Cities, 2017)
NCP 12: Food and feed	Local food production, cultivated crops (production of food in tons or kg per ha/year)	(Connop et al., 2020)
	Surface of community gardens/small plots for self-consumption (ha)	(Connop et al., 2020)
	Vulnerability - lack of local food: diversity of crops	(Camacho-Caballero et al., 2024)
	Vulnerability - lack of local food: population density (hab/km2)	(Camacho-Caballero et al., 2024) (Langemeyer et al., 2019)
	Proximity to urban gardens (network distance (m))	(Langemeyer et al., 2019)
	Neighborhood grocery count (# of grocery stores)	(Langemeyer et al., 2019)
NCP 15: Learning and inspiration	NbS area (area in relation to population, area per captia). Area (m2), Size (ha)	(Connop et al., 2020) (Kato-Huerta & Geneletti, 2022) (EC, 2021)
	# classes visiting	(De Groot et al., 2009)
	# scientific studies	(De Groot et al., 2009)
	outdoor educational activities, # of educational events	(Tudorie et al., 2020) (Watkin et al., 2019)
NCP 16: Physical and psychological experiences	# of visitors, # of people using NbS	(Connop et al., 2020) (Kabisch et al., 2016) (Veerkamp et al., 2021) (EC, 2021)
	Presence of walking paths (walkability)	(Connop et al., 2020) (Tudorie et al., 2020) (EC, 2021)
	Type of surrounding roads	(Connop et al., 2020) (EC, 2021)
	Type of surrounding buildings	(Connop et al., 2020)
	Land use/land cover data	(Connop et al., 2020)
	# of events promoting cultural benefits	(Connop et al., 2020)

	Accessibility: areas with accessibility to NbS at less than 300m, 1000m and more than 1000m, minimum distance to NbS, # and share of people with access to NbS vs # of residents affected by displacement, average distance of NbS from urban centres/train station/public transport (km), NbS proximity to population	(Connop et al., 2020) (Camacho-Caballero et al., 2024) (Kato-Huerta & Geneletti, 2022) (Dong et al., 2025) (Kabisch et al., 2016) (Ommer et al., 2022)
	NbS area (area in relation to population, area per captia). Area (m2), Size (ha)	(Connop et al., 2020) (Kato-Huerta & Geneletti, 2022) (Kothencz & Blaschke, 2017) (EC, 2021) (Ommer et al., 2022)
	Noise attenuation: day-evening-night noise level, average leaf biomass, canopy area of trees and hedges	(Nature4Cities, 2017) (Tudorie et al., 2020) (Ommer et al., 2022)
	Safety: percentage of gender violence, percentage of victimization, number of deaths and missing people, criminal report in the area, number of violent incidents, nuisances and crimes per 100.000 population	(Nature4Cities, 2017) (Kato-Huerta & Geneletti, 2022) (EC, 2021) (Watkin et al., 2019)
	Perceived health, self-rated health and life satisfaction	(Nature4Cities, 2017) (Kato-Huerta & Geneletti, 2022)
	aesthetic value: Number of houses bordering natural areas # users of "scenic routes"	(De Groot et al., 2009)
	Population density (inhabitants/area)	(Camacho-Caballero et al., 2024) (Dong et al., 2025)
	Demographic composition	(Kato-Huerta & Geneletti, 2022)
	Property value	(Kato-Huerta & Geneletti, 2022) (La Rosa et al., 2015) (Watkin et al., 2019)
	%/area of vegetated surfacs, %/area of water surface	(Kothencz & Blaschke, 2017) (La Rosa et al., 2015)
	# of recreation events, increase in # of people engaged in sports, increased physical outdoor activity	(Kabisch et al., 2016) (Veerkamp et al., 2021) (Watkin et al., 2019) (Tudorie et al., 2020)
	Socioeconomic data: schooling, unemployment, employment type and percentage of population with chronic illness, age, or disability	(Dong et al., 2025) (Balzan et al., 2021)
	Deprivation index: Ratio of the number of inhabitants with below-average income per unit area to the total population of the region	(Dong et al., 2025)
	Average income (average income of inhabitants per unit area	(Dong et al., 2025)
	Surrounding greenness (area NDVI >0.18)	(Langemeyer et al., 2019) (Kothencz & Blaschke, 2017)
	Health benefits (monetary): avoided treatment expenditure, avoided income loss	(Jegatheesan et al., 2022)
	Health: incidence of cardiovascular disease (% per year), incidence of obesity (%/year), incidence of chronic stress (%/year), prevalence of autoimmune diseases (%), reduced heat stress (UTCI), air quality improvement	(EC, 2021) (Ommer et al., 2022)
	Mental health: reduced depression and anxiety, attention restoration, recovery from stress	(Tudorie et al., 2020):
	Visual access to green space	(EC, 2021)
	Proportion of elderly residents (%)	(EC, 2021)
	Stakeholder involvement in co-creation/co-design of NbS (#), diversity of stakeholders involved (%)	(EC, 2021)
	Perception of green space based on surroundings outside NbS: Number of building units, % of built-up area, building height variation in a 50 m buffer zone around the NbS	(Kothencz & Blaschke, 2017)
	Availability and equitable distribution of blue-green space (map)	(EC,2021)
NCP 17: Supporting identities	NbS area (area in relation to population, area per captia). Area (m2), Size (ha)	(Connop et al., 2020) (Kato-Huerta & Geneletti, 2022) (EC, 2021)
	# people using NbS for heritage and identity (sense of place)	(De Groot et al., 2009)
	Demographic composition	(Kato-Huerta & Geneletti, 2022)
	Property value	(Kato-Huerta & Geneletti, 2022) (La Rosa et al., 2015) (Watkin et al., 2019)
	Safety: percentage of gender violence, percentage of victimization, number of deaths and missing people, criminal report in the area, number of violent incidents, nuisances and crimes per 100.000 population	(Nature4Cities, 2017) (Kato-Huerta & Geneletti, 2022) (EC, 2021) (Watkin et al., 2019)
	NbS visitation, frequency of visitation	(Kato-Huerta & Geneletti, 2022) (La Rosa et al., 2015) (Tudorie et al., 2020)
	% or # of people owning or maintaining green space	(Kabisch et al., 2016) (Ommer et al., 2022)

	Income Inequality (relative family income, relative percent)	(Langemeyer et al., 2019)
	Ethnic Heterogeneity (diversity, entropy index)	(Langemeyer et al., 2019)
	Surrounding greennes (area NDVI>0,18)	(Langemeyer et al., 2019)
	Community activities, social interactions, neighbourhood attachment	(Tudorie et al., 2020)
	# of cultural events	(Watkin et al., 2019)
	Equal access to green space: household proximity, diversity of incomes	(Ommer et al., 2022)
NCP 18: Maintenance of options	NbS area (area in relation to population, area per captia). Area (m2), Size (ha)	(Connop et al., 2020) (Kato-Huerta & Geneletti, 2022) (EC, 2021)
	Types of uses, # of uses	-

8.2. ArcGIS workflow for the spatial analysis

This section outlines the spatial analysis conducted in ArcGIS. It begins with two general preparatory steps: clipping the data to Amsterdam and creating the Frankendael Park point. It then describes the analyses performed to assess accessibility, demographics, and the equitable distribution of blue-green spaces.

8.2.1. Preparatory steps

8.2.1.1. Clipping the data to Amsterdam

To ensure that all the spatial analyses were limited to the geographic extent of Amsterdam, the relevant administrative boundaries were first extracted from the dataset Wijkbuurtkaart_2024_v1. In the main.gemeente layer via selecting by attribute where the field gemeentenaam (municipality name) equals 'Amsterdam'. This selection was then exported as a new layer named Gemeente_Amsterdam, representing the municipal boundary of the city.

Using this boundary, the clip tool was applied to extract only the Amsterdam portions of the main.buurten and main.wijken layers, resulting in Buurten_Amsterdam (neighborhood level) and Wijken_Amsterdam (district level). The same procedure was applied to the 100-meter resolution grid data (vierkant_100m_Amsterdam) and the OpenStreetMap road network data (roads_amsterdam). These clipped layers formed the foundation for all subsequent analyses.

8.2.1.2. Frankendael park point

Using the PARKPLANSTSOENGROEN.csv file, a point layer was created by using the XY table to point tool. From this, the location of park Frankendael was selected and exported as a new layer named frankendael_park_point, representing the park's geographic location.

8.2.2. Accessibility map

To assess accessibility, network-based buffers of 300, 500, and 1000 meters were created using OpenStreetMap road network data. It was assumed that proximity to the NbS, in this case 300, 500 and 1000 meter, corresponds to accessibility. The closer the buffer to the NbS, the more direct the access. The number of residents within these buffers was then calculated using 100m resolution grid data.

8.2.2.1. Data preparation

The roads_Amsterdam layer was split into two layers based on the attribute layer = 0 (surface roads) and layer ≠ 0 (tunnels, bridges, and elevated roads). These were named Roads_Layer0 and Roads_LayerNot0 and rows with null or empty geometry were deleted. This separation allowed for different connectivity rules to be applied in the network dataset to accurately reflect the physical road structure.

8.2.2.2. Building network dataset

A feature dataset (NetworkData_Amsterdam) was created in the geodatabase using the RD New coordinate system. Two feature classes (Roads_Layer0 and Roads_LayerNot0) were created and the prepared road data was exported to their respective feature class.

A network dataset (Amsterdam_ND_improved) was then created within the feature dataset (NetworkData_Amsterdam), incorporating both feature classes. The connectivity policy was set to 'Any Vertex' for Roads_Layer0 and 'End Point' for Roads_LayerNot0. Travel mode was configured for walking, with length (in meters) as the impedance attribute and U-turns allowed. No restrictions (e.g. one-way streets) were applied to simulate the full accessibility for pedestrians. The network dataset was then built successfully.

8.2.2.3. Creating the network buffers

A new service area layer (Frankendael_ServiceArea) was created using the network dataset. To this layer, the Frankendael park point was added as a facility. The following parameters were set:

- Travel mode: same as in the network dataset
- Direction: away from facilities
- Cutoffs: 300, 500, and 1000 meters
- Output geometry: polygons, standard precision, and rings
- Time settings: not used

After running the service area solver, three polygons were generated representing accessible areas within 300, 500, and 1000m of the park point, following the road network. These buffer polygons were exported as a new layer (networkbuffers_frankendael_saved) for use in further analysis.

8.2.2.4. Calculating the population within network buffers

The vierkant_100m_Amsterdam layer was cleaned by removing grid cells with invalid or missing population values, resulting in vierkant_100m_Amsterdam_clean. The population within the network buffers was calculated using the spatial join tool with the following settings:

- Target feature: networkbuffers_frankendael_saved
- Join features: vierkant_100m_Amsterdam_clean
- Join operation: Join one to one
- Match option: intersect
- Field map: set aantal_inwoners (number of residents) to Sum

The created layer was renamed Networkbuffers_with_population.

8.2.3. Demographic composition maps

Age, income, ethnicity and education level maps were created to assess the demographic composition of the neighborhoods surrounding the park. These maps were based on CBS neighborhood-level data and the previously clipped Buurten_Amsterdam layer.

8.2.3.1. Age: % elderly and children per neighborhood

The Buurten_Amsterdam dataset contained data on age distribution, specifically the percentage of residents aged 0-15 (children) and 65+ (elderly). These attributes (>=0) were extracted to create the layers Children_Amsterdam and Elderly_Amsterdam.

8.2.3.2. Income: average income per inhabitant and % low income households per neighborhood

Income data (Kerncijfers wijken en buurten 2023) and Buurten_Amsterdam were joined with the add join tool using neighborhood names. In the Buurten_Amsterdam layer the attributes for average income per inhabitant and % low income households (>=0) were exported to create the layers Income_Amsterdam and LowIncome_Amsterdam

8.2.3.3. Ethnicity: % non-european origin per neighborhood

The Buurten_Amsterdam dataset contained data on the percentage of residents with a country of origin outside of Europe. This attribute (>=0) was exported to a new layer named NonEuropeanOrigin_Amsterdam.

8.2.3.4. Education: % low, medium, and high education level per neighborhood

Education data (Bevolking 15 tot 75 jaar; opleidingsniveau, wijken en buurten, 2022) and Buurten_Amsterdam were joined with the add join tool using the neighborhood names. New fields (percentage_education_low, percentage_education_medium, percentage_education_high) were added to Buurten_Amsterdam and calculated to determine the percentage education low, medium and, high per neighborhood by: (number of residents with education level / number of residents) * 100. Then these attributes (>= 0 and =< 100) were exported into three separate layers: Low_education_level, Medium_education_level, and High_eduction_level.

8.2.4. Equitable distribution of blue-green space: % children, elderly, and non-European origin within 300, 500, and 1000m network buffers

To evaluate the equitable distribution of blue-green space, the percentage of children, elderly, and residents of non-European origin within 300, 500, and 1000m network buffers of park Frankendael were calculated. These groups were selected based on data availability in the 100m resolution grid dataset, which includes attributes on age and ethnicity. This high-resolution dataset was preferred over neighborhood-level data to ensure more spatially accurate and detailed results.

To determine the share of groups within the 300, 500, and 1000m network buffers around park Frankendael, population totals for each group across Amsterdam were found in their respective attribute statistics. The total number of children was 120960, elderly (65+) 119369 and residents of non-European origin approximately 222300. The latter was calculated by multiplying the total population per grid cell by the percentage of residents of non-European origin.

These totals were used as denominators for calculating the percentage of each group within the buffer zones. A new field was added (e.g. Percentage_children_with_Access) within Networkbuffers_with_population to calculate, for each buffer, the share of a given group relative to the citywide total. For example the percentage children with access was calculated by: (number of children / 120960) * 100. This was executed for each group and the results were exported into three separate layers: Networkbuffers_Children_Access, Networkbuffers_Elderly_Access, and Networkbuffers_NonEuropeanOrigin_Access