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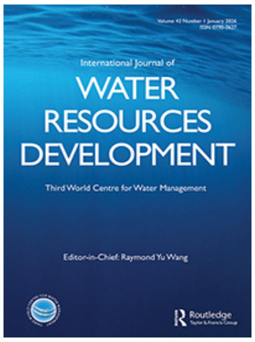

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Supporting justice in cities with nature-based solutions: a spatial decision-making framework applied to Cape Town

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ABSTRACT
Nature-based solutions (NbS) are central to urban resilience efforts, offering climate adaptation benefits alongside social and well-being co-benefits. However, without systematic consideration of socio-spatial factors, NbS implementation may reinforce existing inequalities. This paper adopts a justice-oriented approach to support equitable NbS planning, using Cape Town, South Africa, as a case study. We develop a spatial decision-support framework that integrates ecosystem service demand, social vulnerability, and environmental risk to prioritize NbS types and locations. Results help identify both areas with the greatest need for NbS interventions and the types of NbS most suitable for those areas.

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Nature-based solutions; social vulnerability; climate change; environmental risk; water sensitive planning

Introduction

With over 80% of the world's population living in cities, towns and suburbs (Pesaresi et al., 2016), it is in urban and peri-urban areas where the considerable effects of climate change are likely to be experienced (White et al., 2005), with major implications on how cities are planned and managed. Simultaneously, urban inequalities have been deepening worldwide: income gaps are wider, inter-city disparities are larger and residential segregation is more pronounced (Nijman & Wei, 2020). Other urban trends related to climate impacts such as decreasing biodiversity, increasing urban heat island effect, flash floods combined with justice and urban inequality further pressure urban infrastructure and governance (J. Gonçalves et al., 2025). Having to grapple with these challenges, many cities have turned to nature-based solutions (NbS) as a strategic intervention to becoming healthier, more resilient and more adaptive to climate change (Demuzere et al., 2014; Kabisch et al., 2016; Twohig et al., 2022). Defined as 'actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature' (International Union for Conservation of Nature, 2016), NbS not only have the potential to address environmental issues but also bring additional benefits that enhance the well-being of people in cities by, for example, providing recreational opportunities that enhance physical and mental health, reducing

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heat stress and at the same time providing public spaces to foster social cohesion. In the urban context, biodiversity supports multiple critical ecosystem services including flood control, heat stress regulations and provides recreational opportunities, such as access to green spaces which contributes to community well-being specifically for residents of underserved areas where the access to green spaces is limited. Therefore, biodiversity loss amplifies existing social justice concerns.

Since the 2010s, the implementation of nature-based solutions (NbS) has gained significant traction, largely motivated by their potential to advance urban sustainability and deliver multifunctional benefits (Bauer, 2022). NbS initiatives have been driven by diverse governance arrangements, encompassing top-down approaches orchestrated by public authorities, such as Newcastle's parks and Barcelona's Collserola Park, as well as bottom-up, grassroots initiatives, such as the East Boston Greenway, Leipzig's Roadside Tree Program and Mexico City's Chinampas, a traditional agricultural system (Kiss et al., 2022). Intermediate or hybrid forms of governance have also emerged, illustrated by projects such as the restoration of the Luppe River in Leipzig as well as local initiatives in Latin America, where a diversity of actors was involved, including municipalities, non-governmental organizations (NGOs) and individual citizens, among others (Kiss et al., 2022; McPhearson et al., 2025).

But the surge in NbS projects has not been without criticism. An important and growing body of literature highlights the negative impacts of NbS projects, from the nature-enabled dispossession by the appropriation of land and resources to the unequal distribution of NbS benefits and burdens, often overlapping with existing urban inequalities (e.g., Anguelovski & Corbera, 2023; Frantzeskaki et al., 2025; Raymond et al., 2025; Wijsman & Berbés-Blázquez, 2022). These critical takes on NbS raise questions of justice and equity in NbS implementation, issues still peripheral in NbS literature (Cousins, 2021). While highlighting the potential of NbS to rectify systemic and structural urban inequalities, these emerging debates call for approaching NbS from a critical perspective, integrating concepts of justice and equity into the spatial planning and implementation of NbS (Kabisch et al., 2016; Sekulova et al., 2021). This literature remains mostly conceptual.

Moreover, there remains a significant gap in fully integrating justice and equity as critical considerations into the implementation and spatial planning of NbS through a spatial decision-making framework. Because of the wide range of benefits associated with NbS, assessing their potential is challenging, and various methods and tools have been developed to guide the NbS planning and implementation. A common way to evaluate NbS is through the interdisciplinary concept of ecosystem services (ES) (Prudencio & Null, 2018; Seppelt et al., 2011). By emphasizing the links between nature and human well-being, the ecosystem service concept offers ways to understand and quantify NbS co-benefits (Keeler et al., 2019). Despite its potential for a holistic assessment of NbS, the concept is often used as part of cost-benefit analyses (Ab. Azis & Zulkifli, 2021; Alves et al., 2019), overlooking spatial dimensions and associated contextual socio-environmental specificities that are crucial to addressing justice concerns as well as the successful implementation of NbS. As a result, spatial decisions may be misaligned with the actual needs of the communities they are intended to serve, leading to solutions that are economically sound but practically disconnected from the local social and environmental conditions.

This paper has two interlinked objectives: (1) develop a decision-making framework for planning NbS based on a structured justice lens and (2) enable and support the allocation of NbS based on both social and environmental factors. We develop a spatial decision-support framework for NbS planning that seeks to match the demand and supply for ecosystem services, at the same time prioritizing the provision of NbS based social vulnerability. In order to do so, we differentiate ecosystem services into two groupings: ES that primarily address climate environmental risks (C-ES) and ES that primarily address social vulnerability (S-ES). We applied systematic 'What-if analyses' by manipulating key variables in our framework to explore different scenarios and their corresponding outcomes. In particular, we explore how decisions that prioritize environmental risks over social vulnerability (and vice-versa) influence outcomes. This allows for decision-makers to test alternative strategies and evaluate the potential impacts of different choices and NbS interventions before implementation.

We illustrate the application of the framework using the city of Cape Town, South Africa, as a case study. Cape Town proves particularly interesting from the water-NbS perspective due to recent challenges in securing a stable and resilient water supply and avoiding drought (Holmes et al., 2012; Savelli et al., 2021), while the prevalence of flooding has also increased (City Council of Cape Town, 2020a). Therefore, in this paper we focus on flooding and biodiversity-loss concerns as the primary climate-related urban impacts that influence NbS planning in Cape Town. These risks are particularly significant as the city is facing ongoing hydrological challenges and situated within a biodiversity hotspot. While we also recognize the other climate-related impacts in cities, such as air quality, we did not include them in our framework due to data and scope limitations.

Our findings demonstrate that the proposed framework is effective in; (1) identifying the relative suitability of particular NbS interventions for socially vulnerable areas in Cape Town, especially river restoration projects, urban green spaces and urban agriculture and (2) delineating priority areas for NbS implementation within Cape Town, such as the Kuils River catchment. While these contributions offer valuable guidance for advancing NbS in Cape Town from a justice perspective, the framework should not be regarded as a standalone instrument for defining or operationalizing NbS. Rather, it ought to be integrated into a broader decision-making process that incorporates complementary methods, including expert elicitation and participatory approaches.

Literature background

Justice debates in NbS

Nature-based solutions (NbS) have gained momentum for their promise of climate adaptation, ecosystem-based sustainability and multifunctionality, yet their expansion has drawn criticism. Studies highlight negative impacts, including land dispossession, resource appropriation and unequal distribution of benefits and burdens, often reinforcing existing spatial inequalities (Anguelovski & Corbera, 2023). A typical example in urban areas is the provision of urban green infrastructure, defined as a strategically planned network of (semi-)natural areas (European Commission, 2013), such as parks, green roofs, street trees and even community gardens, which is unequally distributed across dimensions of race, ethnicity and income, with minority communities having lower access to green, thus keeping these groups in vulnerable conditions (Herreros & McPhearson, 2021). Moreover, the provision of green infrastructure has also led to gentrification and displacement of already vulnerable groups while considerably impacting the sense of community of those who remain (Jelks et al., 2021; Wolch et al., 2014). In other words, green infrastructure has often been introduced without proper understanding of the existing community, leading to 'aesthetic upgrades' that increase property values but are disconnected from the preferences and needs of existing residents. Bauer (2022) contributed to this argument by articulating 'environmental privilege' as a tool to further explore the interdependence of justice and greening efforts, drawing attention to the diversity of needs and perceptions regarding urban greening.

While justice concerns initially emerged as critical observations, scholarship is now moving towards structured approaches that seek to define what 'just NbS' should look like. Cousins (2021), for instance, argued that justice remains peripheral in NbS research but stresses the need to embed it as a core principle in both NbS design and implementation. Frantzeskaki et al. (2025) argued for an epistemic shift in NbS planning and implementation that both solidifies interdisciplinary approaches to NbS and fosters transdisciplinary collaborations, where justice is a core guiding principle. Similarly, Arango-Quiroga et al. (2023) introduced the KEIN (knowledge, epistemic injustice and intersectionality in nature-based solutions) framework, which takes a lens of epistemic justice to reveal power relations and whose knowledge and narratives are included or excluded in NbS governance, while Rusca et al. (2024) introduced the plural climate storylines framework to bring together multiple knowledges along four methodological schools: (1) power-sensitive storylines, (2) decolonizing storylines, (3) co-producing storylines and (4) aspirational storylines. In addition, Raymond et al. (2025) extended the debate into the realm of multispecies justice, challenging the anthropocentric orientation of most NbS by advocating for consideration of non-human well-being. We also note contributions that do not focus solely on justice but include justice and/or equity dimensions into broader frameworks for NbS (e.g., Albert et al., 2021).

Because the discourse around NbS is usually linked to environmental and/or climate concerns, scholarship on environmental justice and climate justice becomes particularly relevant. Although both scholarships are related and have evolved in parallel, they stem from different intellectual traditions and emphasize distinct dimensions of justice. Environmental justice scholarship historically emerged from grassroots struggles against localized forms of environmental harm (Schlosberg & Collins, 2014), such as exposure to toxic waste and industrial pollution (Hunold & Young, 1998; Morello-Frosch et al., 2002). More recently, this scholarship has also engaged with issues of unequal access to clean air, waste and water management, and green space (Kabisch & Haase, 2014; Kubanza & Simatele, 2015; Radonic & Zuniga-Teran, 2023; Schwarz et al., 2015). Climate justice, by contrast, has developed more recently in response to the global and intergenerational impacts of climate change (Schlosberg & Collins, 2014). It extends the principles of environmental justice to address questions of responsibility for carbon emissions, the uneven vulnerabilities to climate impacts across regions and populations, and the unequal capacities and agency of countries to adapt to climate change (J. Gonçalves et al., 2025; Schlosberg & Collins, 2014).

Another central development in recent NbS scholarship has been the use of the justice triad as foundational framework, encompassing distributive, recognitional and procedural justice, which help to understand; (1) where injustices emerge spatially, socially and culturally, (2) which part of the society is ignored and excluded to understand who is affected and (3) which processes exist to include the ignored to reveal and reduce such injustices (Jenkins et al., 2016). The three dimensions are not exclusive and should be addressed together, as inequitable distributions of benefits and burdens, lack of recognition and limited participation in decisions, all work to produce and reinforce injustices and claims for justice (Schlosberg, 2007). Reviews such as Kato-Huerta and Geneletti (2022) explicitly apply this triad to evaluate how NbS shape access to resources and decision-making, while Wijsman and Berbés-Blázquez (2022) emphasized the tensions between these dimensions in sustainability pathways, including NbS.

The scholarship highlighted above provides a critical lens. NbS projects are often promoted as interventions that simultaneously address multiple challenges, including climate adaptation and biodiversity conservation. However, without attention to justice, they risk reproducing or even deepening existing inequalities. A focus on environmental risks only may lead to NbS interventions in areas where populations are socio-economically advantaged and have more capacity to adapt or retreat. This is the case, for example, of some coastal areas that house high-income populations (Goncalves et al., 2022). Another example is the focus on biodiversity, leading to NbS measures like protected areas and forest plantations, which can negatively impact local and Indigenous populations, through displacement, livelihood restriction, human rights violations and cultural loss (Chatty & Colchester, 2002; Dowie, 2011; Osborne, 2015; Vanclay, 2017). However, despite these developments, in particular towards a structured three-part justice approach, most studies remain conceptual and do not operationalize justice dimensions into a decision-support framework for NbS planning and design.

Social vulnerability

Social vulnerability is closely linked to socio-spatial inequalities and refers to the characteristics and conditions of populations, systems or assets that increase susceptibility to harm from hazards (UNISDR, 2009). It reflects the potential loss of human and social capital and is shaped by intersecting drivers of inequality, such as gender, class, race, ethnicity, age, disability and sexuality, etc. These intersecting drivers are embedded in cultural norms, institutional practices and political frameworks, making vulnerability a socio-political construct rather than an intrinsic condition (Pereira Covarrubias & Raju, 2020; Raju et al., 2021, 2022). Spatial dynamics play a central role, as inequalities are unevenly distributed across geographies. In urban contexts, in particular, inadequate risk-informed planning, deficient infrastructure and weak social support systems often turn hazards into disasters (Broto, 2017; Raju et al., 2022).

NbS offer pathways to mitigate socio-environmental risks and reduce vulnerability by providing ecosystem services, livelihood opportunities and social benefits (Cohen-Shacham et al., 2016). Conceptually, NbS act through the three dimensions of vulnerability, reducing exposure and sensitivity, and increasing adaptive capacity, thereby influencing both ecological and social resilience (IPCC, 2014). Evidence from sub-Saharan Africa and the Pacific Islands, for example, illustrate the potential of NbS to mitigate hydro-meteorological risks, address major challenges, such as water and food security, and enhance livelihoods and well-being (Enu et al., 2023; Kiddle et al., 2021). However, as highlighted above, the justice dimension is crucial: NbS can inadvertently reproduce inequalities and push people into further vulnerability, if implemented without explicit attention to justice aspects.

Social vulnerability is a multidimensional construct, shaped by interacting social, economic and political factors, rather than a directly measurable quantity. Nonetheless, quantification offers important benefits: it enables prioritization of interventions, monitoring of progress over time and the integration of justice considerations into planning and decision-making.

In the literature, social vulnerability is commonly operationalized through composite indices such as the social vulnerability index (SoVi), indicator-based frameworks or qualitative assessments. SoVi is one of the most widely applied approaches, often relying on principal component analysis (PCA) to capture latent patterns among multiple, correlated indicators (Cutter et al., 2003; Mavhura et al., 2017). PCA leverages existing data, such as census variables, to construct statistically derived dimensions of vulnerability (Apotsos, 2019). However, the approach is not without limitations: the results depend heavily on indicator selection, and the statistical weighting may not always align with theoretical or contextual understandings (Beccari, 2016; Tate, 2012). Transparency in indicator choice and careful interpretation of PCA results are therefore essential.

Nature-based solutions and ecosystem services

Nature-based solutions (NbS) are commonly conceptualized as an umbrella term encompassing diverse but interconnected research domains and practices, including urban forestry, green and blue infrastructure, urban agriculture, ecosystem services, ecosystem-based adaptation and disaster risk reduction, as well as sustainable urban water drainage systems. This breadth has given rise to persistent and often contested debates regarding conceptual boundaries, raising the question of whether the concept of NbS serves primarily to unify or fragment academic and practitioner communities. Indeed, a recent review by McPhearson et al. (2025) identifies the conceptualization of NbS as one of the field’s central challenges. Yet, the authors provide a nuanced synthesis of the literature: They highlight that some scholars advocate for a broad definition that encompasses any ecosystem-based intervention addressing societal challenges, others argue for a more circumscribed framing, and still others contend that the multiplicity of conceptualizations is not inherently problematic; rather, attention should be directed towards the practical implications of how different NbS-related terms and definitions are employed. In this paper, we operationalize NbS as interventions based on the types proposed by the World Bank (2021) framework, which include green buildings, beach and dune projects, wetland restoration and creation, urban green spaces, river projects, urban agriculture and urban forests, linking them to the concept of ecosystem services and adaptation.

Ecosystem services (ES) are a common way to evaluate NbS (Prudencio & Null, 2018; Seppelt et al., 2011). By emphasizing the links between nature and human well-being, the ES concept offers ways to understand and quantify NbS co-benefits (Keeler et al., 2019). Despite its potential for a holistic assessment of NbS, the concept is often used as part of cost-benefit analyses. For instance, Alves et al. (2019) economically quantified the benefits of green, blue and grey infrastructures for flood mitigation purposes, in which NbS are economically quantified, enabling comparison with conventional engineering solutions.

Similarly, Ab. Azis and Zulkifli (2021) investigated the economic benefits of green roofs using cost-benefit analysis to reveal the value of NbS for authorities and decision-makers. Such approaches, however, tend to overlook spatial dimensions and associated contextual socio-environmental specificities that are crucial to the success of NbS.

In response, spatial approaches to ES have been developed as well (Burkhard et al., 2009; Le Clec'h et al., 2016), ranging from multi-criteria (e.g., Koschke et al., 2012) to expert-based methods (e.g., Scolozzi & Geneletti, 2012). An interesting contribution from these studies is the importance of spatially mapping both the supply and the demand for ES. On the one hand, the mapping of ES *supply* helps define strategies for maintaining and managing NbS. This includes identifying priority areas for conservation and defining the institutional scale for managing NbS and their associated ES (e.g., Garcia-Nieto et al., 2015). On the other hand, the mapping of ES *demand* helps to understand what types of NbS are needed in specific locations (e.g., Burkhard et al., 2012; Garcia-Nieto et al., 2015; Nedkov & Burkhard, 2012). By spatially aligning ES supply and demand, appropriate provisions for NbS can be ensured for specific locations which is a step towards addressing concerns of unequal and unsuitable distribution of NbS. However, most studies in this direction still take a utilitarian approach and identify priority areas in terms of (high) demand only. This leads to assessments that prioritize NbS with high demand regardless of whom they serve, thus perpetuating existing inequalities and being agnostic to justice concerns.

Moreover, while ecosystem services are widely used in the literature and practice of nature-based solutions (NbS), it is important to acknowledge that the concept is a social construct and therefore cannot fully capture the complexities of socio-environmental systems. For example, a narrow focus on ES framed solely around climate environmental risks, without integrating social dimensions, risks overlooking issues of equity in decision-making by favouring resource allocation to areas with low social vulnerability, where populations potentially have higher adaptive capacities and resources to mitigate or adapt to climate risks (Goncalves et al., 2022). This is not to say that environmental risks are not important or that areas with low social vulnerability should not be included in NbS planning, but rather that there is a need for improved methodologies that explicitly link NbS to the reduction of social vulnerability, ensuring that interventions alleviate rather than exacerbate existing inequalities.

Methodology

This section introduces the case study and the methodology adopted in the study, starting with an overview and then providing details about the methodology.

Approach and case study

This section describes the approach adopted in this study (see Figure 1). Our methodology consists of two main parts. The first part involves developing a justice-based lens for implementing NbS. The second part focuses on defining a spatial decision support framework for planning the NbS.

We illustrate our methodology in the city of Cape Town, South Africa, which is situated in one of the world's so-called biodiversity hotspots (Cilliers et al., 2013). Recently, this area has been facing more consequences of increasing global climate risk (O'Farrell et al., 2012). In 2018, the city experienced a severe drought, reaching the proverbial Day Zero, where the taps ran dry. As a result, drought-based NbS are specifically being investigated as alternatives to mitigate future droughts in the city (Holden et al., 2023; Orimoloye et al., 2021). The legacy of centuries of colonial and Apartheid rule compounds this, having left the city segregated with many vulnerable populations (Venter et al., 2020). Many of Apartheid's entrenched inequalities still affect ecosystem benefits, such as access to green areas (Venter et al., 2020). These historical events have also shaped the way power dynamics underlie water security, with certain societal groups better placed to influence water systems, leading not only to 'socio-hydrological' inequalities but also unsustainable water use (Savelli et al., 2021). This complex socio-environmental landscape makes Cape Town exceptionally interesting as a case study.

The methodology was applied to a sub-region within the city of Cape Town in a vulnerable area known as the Cape Flats by selecting a limited number of wards in the area. This area is far removed from the urban core of the city, without proper infrastructure or services. Some Cape Flats-wards were excluded due to differing city features (for example, the Philippi farmlands that consist of rural homesteads and small farms, or the Cape Town International Airport), while some wards outside the Cape Flats,

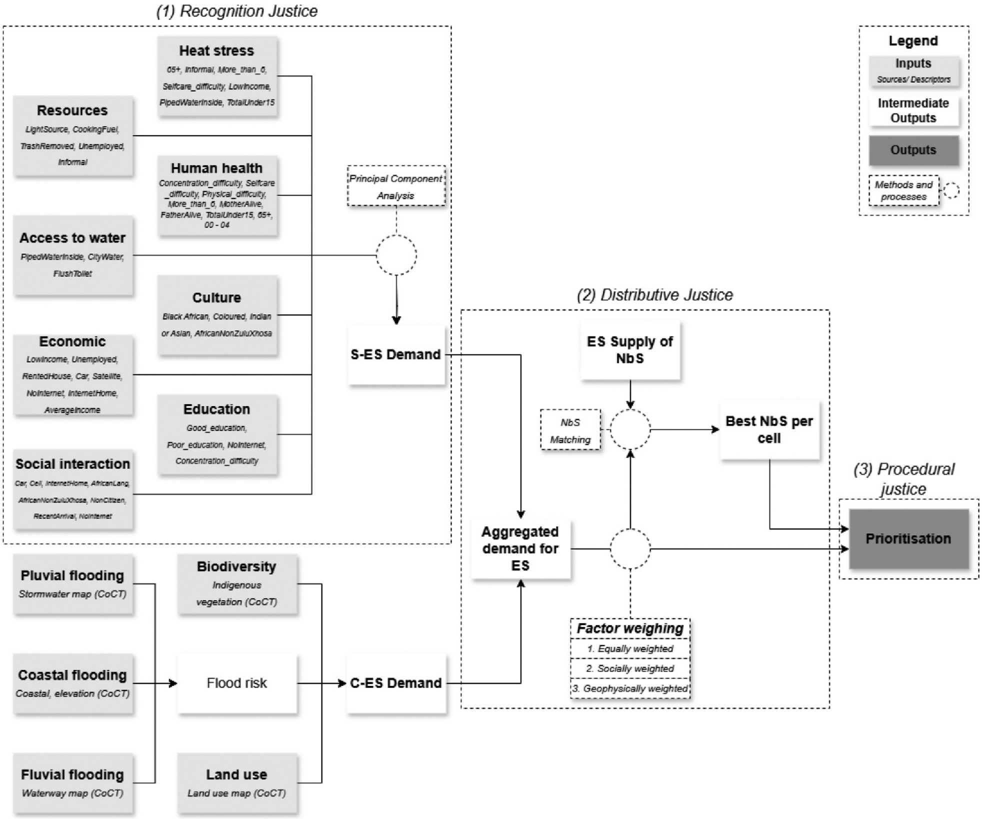

Figure 1. Methodology of the study, showing the main steps where recognition, distributive and procedural justice are incorporated.

in the region of Firgrove, were explicitly included to capture the natural floodplains and dunes in the area. Additionally, the socio-economic differences between the areas allow for insightful context-giving to the range of inequalities within the city.

Justice lens

Following core theoretical concepts of distributive, recognition and procedural justice, our approach takes a structured justice lens: (1) incorporating *recognition* justice through the multi-dimensional estimation of social vulnerability in space, which allows for recognizing local needs and thus prioritizing NbS allocation from a justice perspective, (2) addressing *distributive* justice by allocating NbS based on both climate environmental risks and social vulnerability, ensuring that more vulnerable populations benefit proportionally and (3) centring *procedural* justice by developing a spatial decision-support framework that enables 'What-if' analysis to explore different equity scenarios such as the prioritization of social vulnerability over climate environmental risks and vice-versa.

Spatial decision-support framework for NbS planning

The decision-support framework has four key components; (i) estimating the demand for ES based on social vulnerability, or S-ES demand, (ii) estimating the demand for ES based on climate environmental risks, or C-ES demand, (iii) approximating ES supply for different NbS and (iv) defining an aggregation method for integrating S-ES and C-ES demand matching to NbS ES supply to support more equitable planning for NbS. Social vulnerability and S-ES demand are assessed from census data through principal component analysis (PCA) to account for its multidimensional nature, while the C-ES demand includes flood risks, biodiversity conditions and land use. The supply of NbS is then estimated and matched and prioritized according to the aggregated ES demand. Finally, 'What-if' analysis to determine the influence of giving certain ES more weight than others in NbS matching and prioritization processes.

Demand for ecosystem services based on social vulnerability

The first step in the framework is to estimate the ecosystem service demand based on social vulnerability (S-ES), which allows for recognizing existing inequalities and thus prioritizing NbS allocation from a justice perspective. For that, a social vulnerability index (SoVi) is calculated using principal component analysis (PCA).

In this study, we identified ES demand indicators based primarily on the World Bank (2021) framework. These indicators are grouped into five dimensions to represent social vulnerability (see Figure 2). While there are other methods to determine the indicators such as expert guidance (Bucherie et al., 2022; Katic, 2017), using literature allows for broader and unbiased selection. That being said, there remains a bias inherent to the process of selecting indicators (Melsen et al., 2018). The selected proxy indicators for calculating demand for different ecosystem services are shown in Table 1. The data were obtained from the 2011 South African National Census (see Table A1 in the Appendix in the online supplemental data for an extensive list of data sources). Once proxy indicators have been selected, the correlations among them are evaluated to reveal which variables are more relevant. While, in literature, PCA is used to estimate the ES supply (García-Nieto

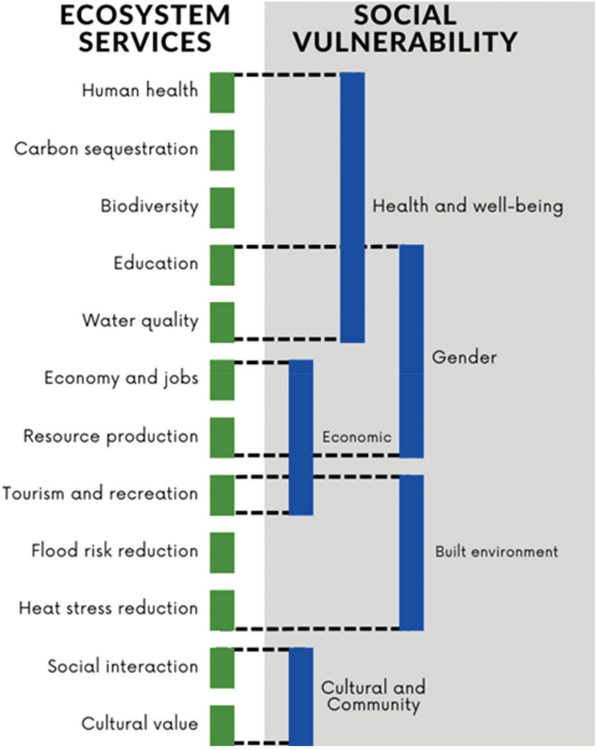

Figure 2. Social vulnerability matrix for ES demand.

et al., 2013; Le Clec'h et al., 2016), the novelty of our approach is that we applied PCA to assess the demand for ES based on social vulnerability in addition to the ES supply.

The use of proxies is necessary because there is no data that 'measures' ecosystem services. In some cases, the link between the proxy and the actual ES that can be provided by an NbS intervention is intuitive, such as *water quality* or *flood risk reduction*. For example, green roofs, rain gardens and wetlands promote sail infiltration which filters and removes sediments, nutrients and heavy metals from water, while at the same time helping to manage storm water and reduce flood impacts ((UN Environment–DHI, UN Environment & IUCN, 2018).

In other cases, the proxy serves to represent a certain aspect of social vulnerability: for example, while *education* and *economy and jobs* are both approximated by *internet access*, it does not mean that *internet access* is an ecosystem service, nor that it can be provided by NbS. Instead, it means that locations where *education* or *economy and jobs* is a vulnerability will benefit more from NbS that also include educational and economic co-benefits. Such an approach helps us to better include local, contextual needs into NbS planning and, thus, address recognition justice concerns raised earlier.

Figure 2 illustrates the conceptual connection between ES and how those can help reduce the social vulnerability to climate change. This conceptualization allows for understanding how different dimensions of social vulnerability, such as *Health and well-being*, can be alleviated by NbS that offer specific ES, such as direct improvements to human health,

Table 1. Indicator selection for ecosystem services in relation to NbS implementation.

S-ES	Proxy data	Relevant literature	Relevance to NbS
Human health	Concentration difficulty, selfcare difficulty, physical difficulty, Household size, Parents alive, Total under 15 years old, Total over 65 years old	Cutter et al. (2003); Eisenman et al. (2016); Otto et al. (2017)	NbS improve local environmental quality and access to green space can support health and well-being.
Education	Good education, Poor education, No internet, Concentration difficulty	Apotsos (2019); Tapia et al. (2017)	NbS improves adaptive capacity and access to environmental knowledge and education.
Water quality	Piped water inside the house, Access to city water, Flush toilet	Ngarava et al. (2022); Tapia et al. (2017)	Related to access to reliable water infrastructure. While not a direct measure of water quality, NbS can improve water quality and access through infiltration.
Economy and jobs	Low income, Unemployed, Rented house, Car ownership, Satellite TV, No internet, Internet at home, Average income	Tapia et al. (2017); Vanclay (2002)	NbS provide financial benefits to surrounding communities.
Resource production	Non-electric light source, Fuel for cooking, Trash removed, Unemployed, Informal house	Apotsos (2019); Ngarava et al. (2022); Vanclay (2002)	NbS provide resources, such as fuel or even food, to local communities.
Tourism and recreation	Included in Economy and jobs, and Human health	Out of scope	See 'Economy and Jobs' and 'Human Health'
Heat stress reduction	Total over 65 years old, Informal house, Piped water inside the house, Total under 15 years old, Low income	Eisenman et al. (2016); Reckien et al. (2017)	NbS significantly mitigate the urban heat island effect in the immediately surrounding area.
Social Interaction	Car ownership, Cellphone ownership, Internet at home, African Language speaker, African (non-Zulu, Xhosa) speaker, Non citizen, Recent arrival, no internet	Apotsos (2019); Tapia et al. (2017); Vanclay (2002)	NbS provide benefits to increase engagement and interaction between different groups.
Cultural value	Black African, Coloured, Indian or Asian, African (non-Zulu, Xhosa) speaker	Tapia et al. (2017); Vanclay (2002)	NbS can provide cultural value to diverse local communities. See also 'Social Interaction'.
C-ES	Indicators	Relevant literature	
Flood risk reduction	Fluvial, pluvial and coastal flood maps	Reckien et al. (2017) Twohig et al., 2022	Related to exposure to floods. NbS can mitigate these risks
Carbon sequestration	Not considered	Reynolds et al. (2017)	Out of scope: NbS can offset carbon emissions.
Biodiversity	Indigenous vegetation	Seddon et al. (2020)	Related to ecological diversity. NbS enhance habitat quality, and quantity.

education, water quality improvement and so forth. For example, this helps frame how a given NbS, such as a wetland restoration project, can improve local water quality through natural filtering (ES), improving the health and well-being of a local community that relies on this as a source of drinking water (reduction of social vulnerability; Prasanya et al., 2024).

Demand for ecosystem services based on climate environmental risks

Environmental factors result in demand for ecosystem services in certain places. This can take the form of physical phenomena, such as flood risk or indigenous fauna and flora, that impose ES demands for flood mitigation and increased biodiversity, respectively. In this study, only certain C-ES were considered: flood risk reduction, biodiversity and heat stress reduction. How these demand factors were calculated is explained in this section (apart from heat stress reduction, which is determined from a set of indicators selected as described in the previous section). Additionally, the implications of land-use on NbS matching and selection are also discussed.

Approximating flood risk. The flood risk for different areas were determined to ensure environmental factors were taken into account in ES demand and NbS matching. The City of Cape Town is affected by three types of flood risk (City Council of Cape Town, 2020a):

(1) Pluvial flooding (rain).
(2) Fluvial flooding (rivers).
(3) Coastal flooding (ocean).

Each of these three types of flooding have different dynamics regarding frequency, damage and mitigation – emphasizing the value of considering these dynamics as separate risk types, particularly as different NbS address different flood risk types. The field of flood risk modelling is a well-developed research field, with many complex models being able to establish flood risk maps from various sources. For this analysis, however, simplified versions of these maps were used as proxies, as the focus of the analysis lies in understanding the impacts of justice considerations. The following proxies were used for each type of flood risk:

(1) Pluvial flooding – Stormwater waterbodies in Cape Town.
(2) Fluvial flooding – Open watercourses.
(3) Coastal flooding – 5 m Contour lines of Cape Town.

This low threshold was used based on available data sets provided by the City of Cape Town Open Data Portal. This course granularity limits coastal flood risk accuracy, as the height above sea-level is only available in 5 m increments. Accordingly, the precision of the impact of sea-level rise, and so coastal flooding risk, is limited by this granularity.

Capturing biodiversity as an ES. Biodiversity was included by leveraging a simplified proxy indicator: the indigenous vegetation coverage provided by the city of Cape Town (City Council of Cape Town, 2020b). Depending on the degree of coverage by indigenous vegetation, the biodiversity demand score would be higher or lower.

Incorporating land-use restrictions on NbS. By using the publicly available land-use map of the City of Cape Town, in accompaniment with building ordinances (City Council of Cape Town, 2020b, 2016), the regulatory barriers towards certain NbS were incorporated into the model (Tables A2 and A3 in the online supplemental data). This accordingly scopes NbS matching to include regulatory limitations, for example, ordinances that specifically prevent agricultural activities.

ES supply of NbS

Using a set catalogue of NbS for Cape Town, a binary ES supply profile for each NbS was created based on literature and existing frameworks (World Bank, 2021) – meaning that each NbS was assumed to either supply a given ES completely, or not at all (Figure A1 in the online supplemental data). This greatly simplifies the complexity behind the benefits provided by different NbS, and the complexity of the nature of NbS themselves, but also provides a practical simplification for this paper. In practice, NbS remain difficult to discretely categorize, with many different designs and characteristics that vary with local biodiversity and context. By selecting the NbS types, and their associated ES, referred to in the World Bank (2021) framework, we ensure that our findings remain translatable to existing frameworks of urban NbS planning and implementation. NbS that were considered are green buildings, beach and dune projects, wetland restoration and creation, urban green spaces, river projects, urban agriculture and urban forests.

ES aggregation and NbS matching

To distribute more appropriate NbS to specific areas based on the ES demand profiles of those areas, a matching model is presented to incorporate these factors into a clear preferred NbS for each area. This requires a) additional spatial sampling of data, b) combining S-ES and C-ES demand factors into an ES demand profile for each cell and c) matching NbS supply profiles to area demand profiles, as explained below.

Spatial sampling of ES demand. As the data sets used consisted of granular data, such as the various flood risk maps, and others provided data aggregated on a ward level, such as the socio-demographic data, all data were spatially sampled into uniform square cells of 100 m by 100 m. This size allows for capturing multiple households and geographic features, while still yielding useful insights and remaining computationally feasible. These square cells were then populated with data from the various sources described throughout this chapter. As ward-level data was normalized, each cell directly inherited the same data values from the ward it was located in. For cells that were located over multiple wards, the data values were averaged proportionally to the area of each ward present in the cell. This also allowed for smoother transitions between ward boundaries.

Aggregating ES demand profiles for cells. As a result of using PCA, the S-ES demand factors were already normalized to a scale of [0,1]. C-ES demand factors, such as flood risk, were also normalized to [0,1], where factors such as land-use were Boolean (either allowed or not). With all factors normalized, each sampled cell had its own unique ES demand profile, with a value of [0,1] for each ES factor. From these values, the aggregated ES demand was determined as a weighted sum with different weighting schemes.

Matching ES demand to supply. With an ES provision profile for each NbS, each NbS was matched to the ES demand. A matching algorithm (Algorithm 1 in the online supplementary material) was developed that, based on a predetermined weighting of ES, determines which NbS is best able to accommodate the varying ES demands of a given area. We refer to this NbS as the *preferred NbS* for each cell.

Differently put, the NbS matching model compared the ES demand profile of each cell and matched it to the NbS of which ES supply profile best meets these demands. By assessing differences between the ES demand values of a cell and the ES supply values of a given NbS, the NbS with the smallest differences were selected. Here, geographical limitations, such as proximity to the shore for beach and dune projects, and restrictions for conservation areas, were also considered. The former is implemented through a simple proximity to the coast requirement and is important to prevent the NbS model from selecting beach and dune NbS in regions far from the coast, where they would be practically infeasible. The conservation restriction is also necessary, as conserved land is often not available for redevelopment with NbS, and has a more complex relationship in providing certain ES. For the purposes of this paper, conservation was excluded as an NbS for two reasons. Firstly, the approach taken heavily favours proximity-based ES provision. ES demand and ES supply are both determined spatially, and non-local effects such as carbon sequestration are excluded from the scope. Typically, in the South African context, a relatively hard-line conservation-paradigm is followed, with access to conserved areas often being limited. Secondly, while conservation areas certainly provide even local ES to the nearby population, this is excluded from the scope of the analysis in favour of investigating the effects of other, more accessible urban NbS. In this algorithm, no NbS was selected for cells in conserved land.

Prioritizing high ES demand cells. The prioritization factor, selected at 10% for this study, has a twofold impact on model results: firstly, in generating a usable and interpretable sample of model recommendations, although this impacts, and secondly in how that affects the prevalence of certain preferred NbS in model outputs. By analysing the sensitivity of this prioritization factor, the impacts of this prioritization factor on model outputs can be determined (Figure A2 in the online supplemental data).

The error between successive iterations of a smaller and smaller prioritization factor in terms of coverage, calculated using Equation (1), leads to the average change in overall coverage ratio for all NbS if the number of prioritized cells is decreased.

$$E_p = \frac{1}{N}\sum_{N}^{NbS}\left(NbS_p - NbS_{p-1}\right) \tag{1}$$

The prioritization proportion becomes more sensitive as more cells are excluded. To select a prioritization proportion in a relatively stable range of operation, while still making a meaningful exclusion of non-prioritized cells, a prioritization proportion of 90% was selected. This means that the cells that had the top 10% of aggregated ecosystem service demand were considered as priority cells. This prioritization assumes that those areas with more ES demand require more attention and resources. While this seems straight-forward, this potentially excludes minority groups with high ES demand if they are located in areas that might overall have a lower ES demand.

'What-if' analysis

A 'What-if' analysis was conducted to systematically explore different scenarios and their corresponding outcomes by manipulating key variables in our framework. In particular, we explored the impact of decisions that prioritize environmental risks over social vulnerability (and vice-versa), providing insights into the justice implications of decision-making in this context. This allows for decision-makers to simulate alternative strategies and evaluate the consequences of different choices and NbS interventions before they are implemented.

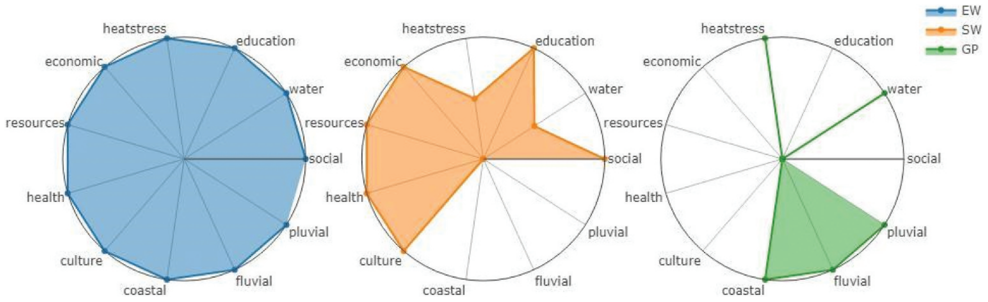

Figure 3. Three scenarios and respective ES weights considered in the 'What-if' analysis.

The 'What-if' analysis was based on three different value-weightings for different ES demands, shown in Figure 3: a base case, with all ES factors equally weighted (EW case), a 'social valuation' case, where S-ES, such as *education and health*, were given larger weights (SW case) and one environmental valuation case, where only physical ES such as *pluvial, fluvial and coastal flood risk* were considered (GP case). These analyses showed the implicit complexity when considering both social vulnerability and climate environmental risks in NbS decision-making.

Results

Ecosystem service demand

In Figure 5, the different types of ES demand are shown for the Cape Town area, with the normalized demand value being plotted for each ward. A value close to one (yellow) represents a high demand for a given ES, while a low value (dark blue) represents a low or zero-demand for an ES. From these maps, the difference in distribution of demand factors becomes clear: some ES, such as social interaction, are much more widely demanded than other ES such as water on a relative scale, while the spatial distribution of each ES demand provides insight into different ways in which populations are socially vulnerable. Notably, there is a clear difference between the more vulnerable Cape Flats area (circled in orange), and the less vulnerable and more developed Atlantic seaboard areas (circled in red) in Cape Town – illustrating the spatial and multi-dimensional nature of the city's inequality. Spatially, we see that the distribution of ES demand varies greatly from one area to another. The degree of this variation depends on the ES in question however – where some ES demands have larger variations (such as a demand for resources) compared to other ES (such as a demand for culture). This is particularly useful to consider aspects of recognition justice in the city, as the varying needs of different types of ES are considered. This is also crucial for incorporating distributional justice as the multi-dimensional ES demand is used to determine the best distribution of NbS to meet the ES demand.

Looking deeper into how each ES demand factor was determined with PCA allows for a better understanding of how the underlying components affect the calculated factor. In the case of the *social*-ES demand factor, the factors shown in Figure 4 were used as inputs with their resulting PCA-loading weights (see Table 1 for a full list of factors). This suggests that Internet at Home/No Internet and Car ownership arguably influence social interaction

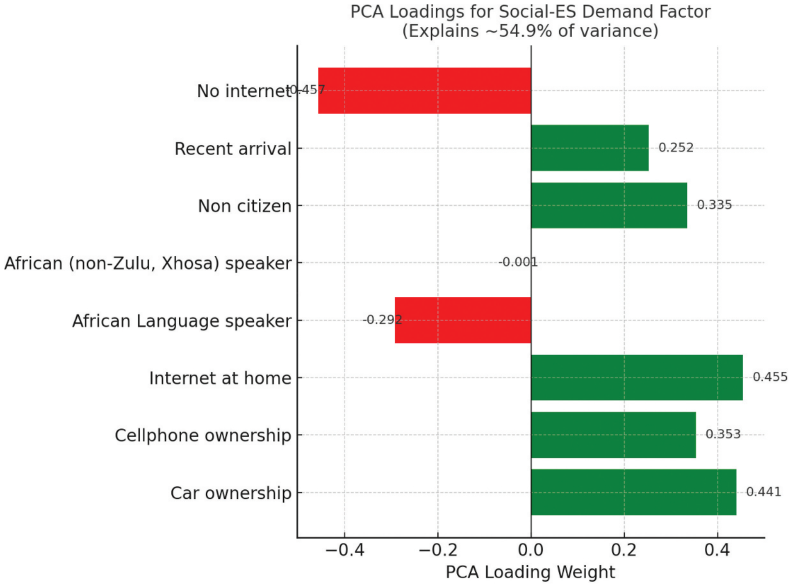

Figure 4. PCA loadings for social-ES demand factor.

as an ES the most in this framework, while being an African (non-Zulu, non-Xhosa) speaker arguably does not. Overall, the *social*-ES demand factor explained approximately 54.9% of all the variation in the selected feature, reflecting the relatively correlated feature data and small dimension size from which the factor was generated.

NbS preference map

After determining ecosystem service demand, these demands could be matched to specific nature-based solutions that offered those ecosystem services and then prioritized based on the highest 10% of aggregated demand for ecosystem services (Figure A3 in the online supplemental data). This prioritization factor is selected as 10% based on a sensitivity analysis of the impact of prioritization on NbS selection error. In Figure 6, the results of this analysis are presented for all cells under consideration (6a) and for those cells with the highest demand, or priority, for ecosystem services (6b).

Overall, in both cases, we observe that certain nature-based solutions dominate – particularly river projects for the water ways (blue), and urban green space (dark green) and urban agriculture (light green) elsewhere. In particular, we see how the course of the Kuils river is most suitable for river projects (Figure 6a, i), while urban agriculture is particularly preferred over the agriculturally zoned area close to the Macassar dunes (Figure 6a, ii). Additionally, the only places where beach and dune projects are recommended are on the banks of the Helderberg marine protected area (Figure 6a, iii), due to its low elevation above sea level. When these NbS are prioritized for aggregated ES demand (Figure 6b), however, we see a few pockets that have the highest demand for their respective NbS. This indicates that, while each cell has its preferred NbS, some areas have a higher ES demand for certain NbS.

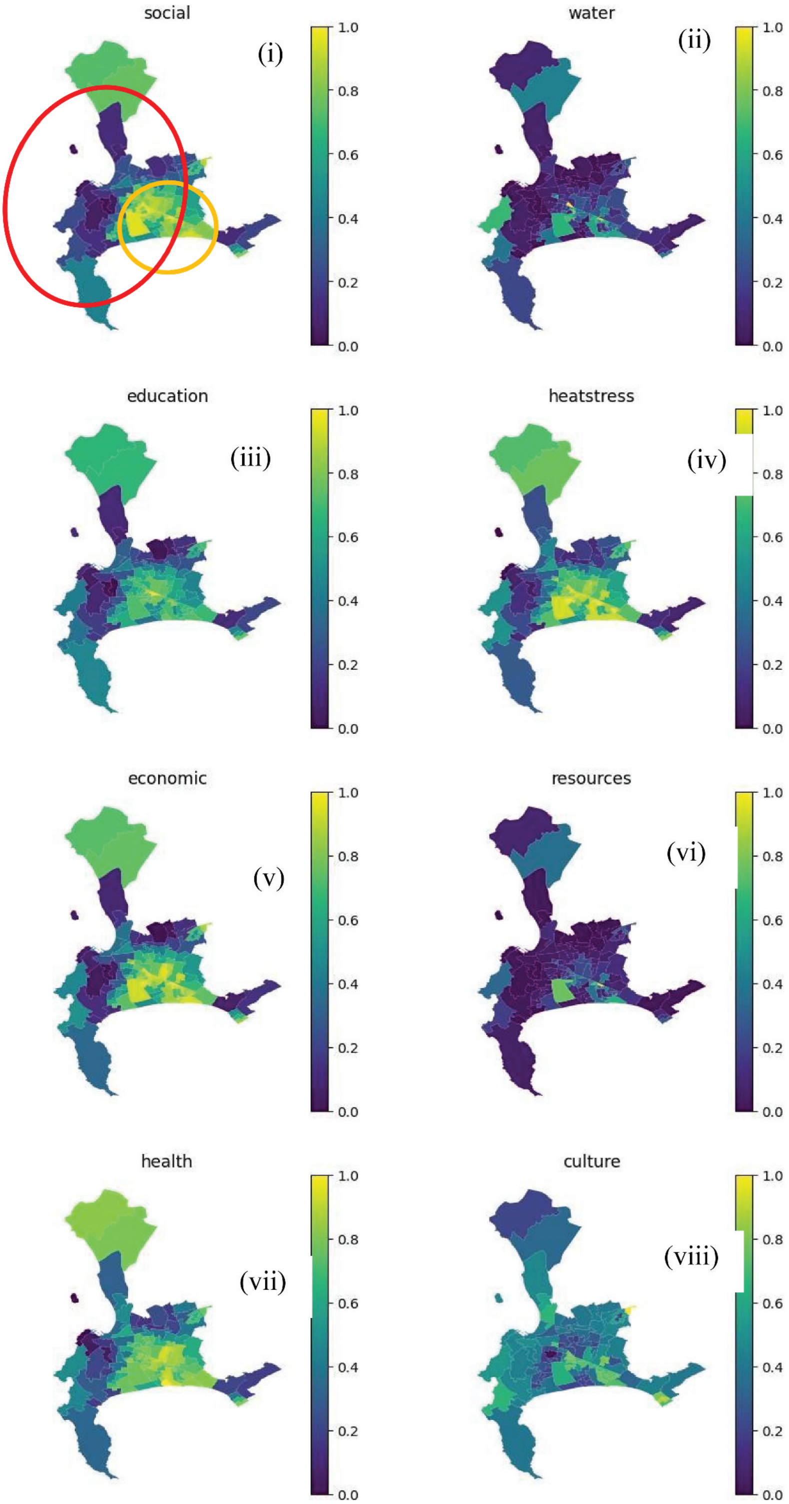

Figure 5. Social demand for ES in the larger cape town area.

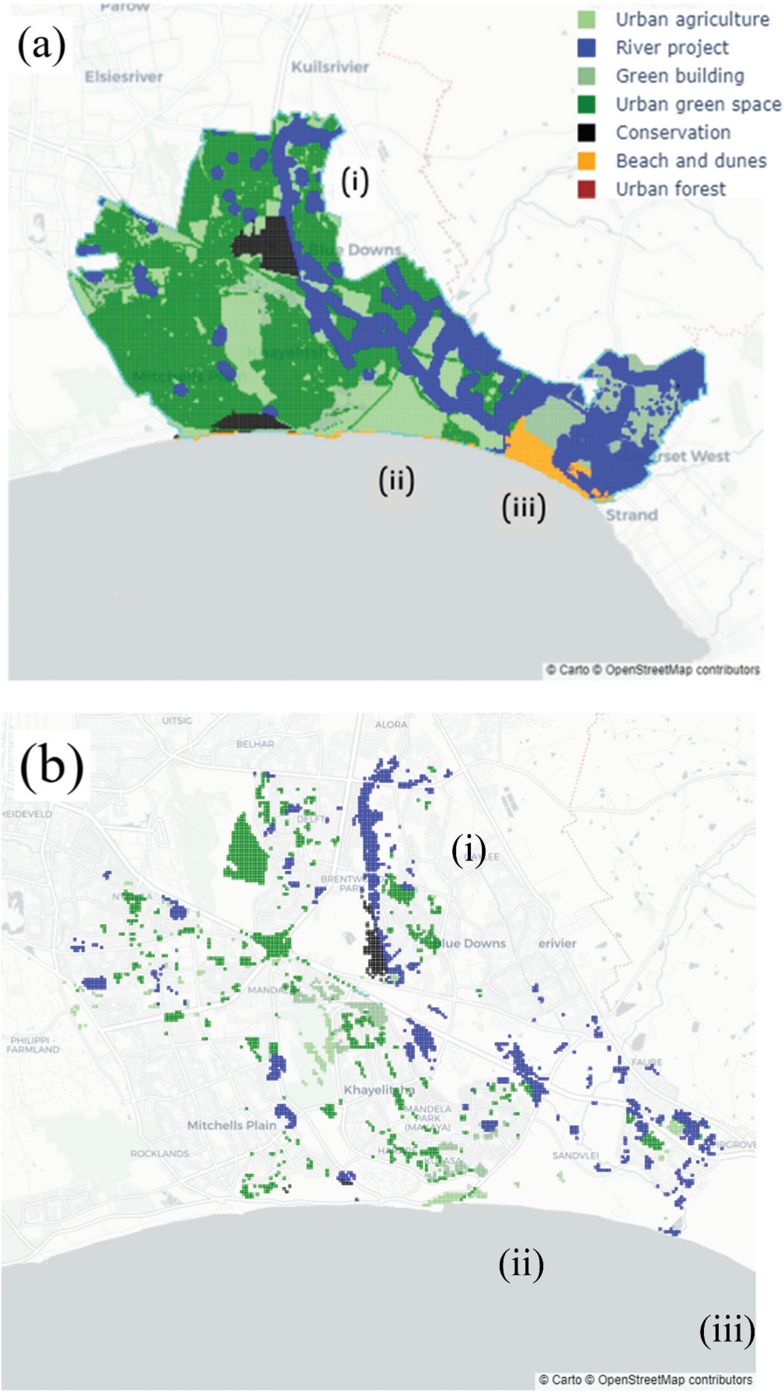

Figure 6. Selected NbS (a) and prioritized NbS (b) of the Cape Flats area in Cape Town.

Here, distributional justice is incorporated by the selected NbS for each cell based on its ES demand profile. Furthermore, the selection of prioritized cells helps decision-makers in considering the places with highest ES demand, strengthening procedural justice.

'What-if' analysis

Table 2 represents the results of a 'What-if' analysis – where we see the impacts on NbS coverage over the entire area of analysis, as well as the prioritized areas, when the valuation of different ecosystem services are changed based on different weighting schemes. This serves to highlight the interactions between groupings of ecosystem services (ranging from more *socially* related ES, to more *environmental* ES) and the respective NbS. From this table, urban agriculture and urban green space solutions appear to target social demands more (50.94 and 42.60 for agriculture, total and prioritized, respectively, and 31.94 and 51.69 for green space, total and prioritized, respectively), as these are selected by the socially weighted scheme and result in a higher aggregate ES demand factor. Wetlands, on the other hand, target environmental demands (flooding, water quality and heat stress) more – indicating that it provides fewer social co-benefits (64.80 and 87.64 for wetland, total and prioritized respectively).

Additionally, it is interesting to see which NbS are not preferred in these areas at all. Urban forests, for example, were never the primary suitable solution and were not included in Table 2. This exclusion comes from the ES supply profile of urban forests that are closely aligned to that of urban green space, but falling short in terms of a few ES, namely social interaction and economic stimulation. Here, categorizing NbS in discrete groups clearly impacts the model results. Some urban forests might potentially provide more social interaction than some urban green space due to contextual factors. Indeed, this is often seen as the case with the culturally and socially important Tokai Forest (Ernstson, 2013). This again illustrates the importance of contextualization, while also calling for a more flexible model in terms of NbS categorizations.

Other solutions, such as beach and dune projects, remained at low coverage due to additional constraints on beach project placement (on the coast). Conservation (black in Figure 6) is still present in all scenarios, as new NbS projects cannot be implemented on land that is already zoned for conservation purposes. While these areas might already be providing ES to the surrounding communities, it is clear from the prioritization analysis that those communities still have a significantly high demand for ES. For the decision-maker, this means that some areas marked as conservation areas can be socially vulnerable. While NbS implementations are useful in other areas, here focus should be on

Table 2. Impacts of weighing schemes on NbS selection and prioritization.

NbS	Equal total	Weighted priority	Social total	Weighted priority	Environmental total	Weighted priority
Green building	8.22	2.99	6.44	0.45	30.42	7.74
Beach and dunes	2.20	0	2.59	0.58	1.18	0
Wetland	3.54	0.22	2.91	0.06	64.80	87.64
Urban green space	41.21	22.47	31.94	51.69	0	0
River project	25.21	65.46	2.20	0.58	0	0
Urban agriculture	16.64	4.24	50.94	42.60	0.63	0
Conservation	2.97	4.62	2.97	4.62	2.97	4.62

making the ES of the conservation area accessible to the nearby communities, without compromising the biodiversity of the area

Discussion

In this study, we proposed a decision support framework for the planning and implementation of nature-based solutions (NbS), with a focus on prioritizing both social and environmental factors. A key aspect of our approach is the integration of justice considerations across the dimensions of recognition, distributive and procedural justice. Recognition justice is incorporated through the spatial estimation of multi-dimensional social vulnerability through ES demand. We used the SoVI to identify the S-ES demand. By mapping the abstract ecosystem services provided by NbS into the existing vulnerability frameworks, we aim to deepen the understanding of the relationships between NbS and social vulnerability. This approach underscores how the selection and placement NbS can be adapted to address the needs of communities that have been historically under-served by public services or disproportionately affected by climate impacts. Distributive justice is introduced by matching NbS based on both S-ES and C-ES demand factors, ensuring more vulnerable populations are considered. Finally, procedural justice is included through the decision-support framework of prioritization of NbS selection, in contrast to conventional NbS planning methodologies that tend to prioritize interventions based on cost-benefit analyses.

Furthermore, the proposed decision-making framework offers a systematic, transparent and data-driven approach for the spatial suitability analysis of NbS. This allows for the identification of areas at neighbourhood scale that are most appropriate for specific types of NbS interventions. Although policymakers in Cape Town have shown interest and commitment in using NbS as a climate mitigation tool (City Council of Cape Town, 2020a; City of Cape Town, 2018), they currently lack the necessary tools to prioritize and select NbS interventions based on social demands and vulnerabilities of the local population. This highlights the critical need for our framework to guide spatial decision-making processes in NbS planning. In terms of the case of Cape Town, river projects, urban green space and urban agriculture address the needs of vulnerable populations in the Cape Flats better, according to this approach. With the incorporation of various land-use and land feature maps, other important factors such as zoning regulation, technical NbS requirements, and existing conserved areas could be considered. While some of these maps, such as flood risk maps, were simplified proxies of actual flood risk, the modular nature of this NbS model allows for easily improving these dependent models later. In the case of urban agriculture, for example, community farms and vegetable patches have often been implemented in historically under-served communities with limited or no success. These results should thus only serve as an indicator of where these NbS are most demanded, but if this demand is adequately met by an actual NbS depends on the implementation trajectory itself.

From the ‘What-if’ analysis, the impact of different value-weightings of ES is made clear. Shifting from a more socially-weighted to environmentally-weighted scheme significantly affects the type and location of prioritized NbS. For policy makers, this provides valuable insight into how different approaches and valuing mechanisms affect decision-making. The opportunities of this approach to allow for coordinated approaches for NbS implementations also mitigates often encountered limitations and shortcomings encountered during the implementation phase of NbS in urban areas.

More research is needed into the interaction of NbS with conservation, as the provisioning of certain ES might be affected by the conservation status of a given NbS (such as resource production in protected forests, for example). Aligning with conservation provides access to more resources and institutions for NbS implementation – partly due to South Africa's well-evolved conservation sector (Holmes et al., 2012; O'Farrell et al., 2012). Protecting biodiversity in this way also results in increased NbS resilience.

Limitations and opportunities for future research

A core limitation of this approach rests at a fundamental level of how NbS are classified and considered. In this paper, NbS were categorized into discrete groups based on certain shared characteristics. While this discretization is often done in literature to facilitate study and planning (World Bank, 2021), as well as comparison among and within cities, it does not necessarily accurately reflect the broad range of various characteristics that specific NbS implementations might have. This is also applicable to the scale at which NbS are considered for this paper; for this approach NbS are considered as isolated entities that function independent of each other, when in reality many multi-scale dynamics and interactions also influence their performance (Bridges et al., 2021; Slinger, 2021).

Moreover, the model only considers the spatial dimension of ES demand and NbS supply, and thus neglects the temporal dimension, which is particularly important for NbS and ES that change over time (Kabisch et al., 2016; Langemeyer & Connolly, 2020; Slinger, 2021). Furthermore, some geo-physical concepts, such as flood risk and biodiversity, were implemented relatively simply – potentially limiting the results of the model to the usefulness of these simple mappings themselves. It remains important, however, that the results of this study be further validated through additional analysis of expert opinion, as well as community insights. The inclusion of more precise C-ES dynamics, such as the impact of urban recharge areas on drought and flood mitigation, would allow for more comprehensive and better-informed modelling. Similarly, other social factors such as heat stress are included as a social vulnerability indicator but not spatially analysed. Future extension of the framework could integrate detailed heat stress and other spatially relevant climate related stresses to enhance local decision-making on NbS implementation.

We highlight that the largest ecosystem in the Cape Town area, the surrounding ocean, was not considered in this study. Although out of the scope of this study, many ES are derived from ocean ecosystems, such as resource production, recreation and cultural and social value, making it an opportunity for future research. NbS have been applied in aquatic contexts in Cape Town (City Council of Cape Town, 2020a) and might impact results of this study through additional benefits that are enjoyed by communities within close proximity to the ocean. This also holds for other existing NbS that were not incorporated into the model. Additionally, carbon sequestration was not considered in this approach due to the relatively local scale of the analysis. Further research could explore the potential air quality benefits from NbS as an additional ES demand.

There is also much debate over the value and risks associated with the calculation of social vulnerability and related indices (Bucherie et al., 2022; Katic, 2017; Vincent, 2004).

The framework that this study uses is no different – which is made clearer for some ES, such as culture, that are typically difficult to define and measure. How ES demand was framed in terms of social vulnerability to climate change is also important; different framings might also be realistic but produce different results.

Related to the above are limitations related to the data used. As the results of the most recent South African census have not been published at the time of writing this study, data from the 2011 census had to be used – potentially yielding recommendations that are no longer applicable. This is, however, easily addressed as soon as newer census results become available. We also note that the use of census data in itself comes with epistemological limitations, as standardized data cannot represent lived experiences, resonating with long-standing debates in planning and geography (J. E. Gonçalves et al., 2024; Schwanen & Kwan, 2009) as well as with epistemic justice concerns in NbS literature (Arango-Quiroga et al., 2023; Frantzeskaki et al., 2025; Rusca et al., 2024).

Indeed, the importance of community engagement and situated approaches that consider the multiplicity of knowledge cannot be overstated. Like each community and neighbourhood, each NbS implementation is unique and different, and must be treated as such. Involving the community allows for an understanding of how these NbS implementations might be different, and how the process should be adapted to meet the community’s needs. Literature highlights the importance of contextual knowledge, inter- and transdisciplinary collaborations, as well as methods for bringing together multiple knowledges in NbS planning and implementation (Arango-Quiroga et al., 2023; Bauer, 2022; Frantzeskaki et al., 2025; Rusca et al., 2024). Supporting literature also shows that engaging communities in urban projects creates trust and leads to a sense of ownership (J. E. Gonçalves et al., 2024), which is important when it comes to sustaining NbS in the longer term (Kiss et al., 2022), while also highlighting constraints and blindspots that hinder inclusive governance of NbS (Wamsler et al., 2020). This also extends to the prioritization of certain areas over others through the aggregated ES demand calculation.

Finally, we stress that the decision-support approach should be taken as what it is: a supportive planning tool rather than a definitive and complete solution of the NbS implementation process. Its impact and the results it yields depends on being embedded within broader decision-making processes that engage a wide spectrum of actors, including experts, practitioners and local communities. Moreover, careful attention must be paid to the role of power relations, which shape both the design and outcomes of NbS interventions, an issue of general relevance (Arango-Quiroga et al., 2023; Rusca et al., 2024), but one that is particularly important in contexts such as Cape Town, where the interplay between water security and urban development has been historically shaped by political dynamics (Savelli et al., 2021).

Conclusion

By using an explicit justice approach to support the implementation of NbS in urban settings, we developed a spatial decision-support framework for NbS planning along both climate risk and social vulnerability axes. The framework allows for spatially mapping both ES supply and demand, while including the social dimension in prioritization through social vulnerability – resulting in a more just approach towards urban NbS planning. In the presented case study of Cape Town, South Africa, this framework prioritizes the use of river projects, urban green space and urban agriculture among other NbS for certain vulnerable areas.

Future work can involve improving the existing approach through incorporating more accurate flood risk and biodiversity models and air quality, for example, but can also expand on the scope of this work. When using a catalogue of all existing NbS within Cape Town, the framework can be used to assess their existing impact in terms of social vulnerability, and potentially serve to shed more light on how ES benefits are distributed spatially for different groups. Furthermore, by incorporating non-local dynamics of NbS over a city scale, NbS and their geographic locations can be better valued in terms of green corridors, biodiversity connectivity and air quality improvement. These concerns can also be addressed by incorporating a system-level view of NbS – which allows for capturing multi-scale dynamics and valuations of NbS. This notably requires redefining and recategorizing different types of NbS and their respective benefits and disservices. Repeating the decision-support approach presented here with a different case study will also allow for additional insights into the generalizability of the approach, and potential inter-city comparisons. Finally, while mentioned briefly in this work, the complex relationship between conservation and urban NbS must be further investigated in order to better understand the co-benefits and trade-offs that arise when assessing the biodiversity-social vulnerability value conflict.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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