Article:

Uribe-Aguado, J., Patiño, J.N., Kozak, D. et al. (2 more authors) (2025) A decision support tool for the selection of biophysical methodologies to assess urban Nature-based Solutions using regulating ecosystem services. Urban Forestry & Urban Greening. 128842. ISSN 1618-8667

https://doi.org/10.1016/j.ufug.2025.128842

A decision support tool for the selection of biophysical methodologies to assess urban Nature-based Solutions using regulating ecosystem services.

Author names and affiliations:

Juliana Uribe-Aguado
Universidad de los Andes Colombia - Department of Civil and Environmental Engineering. PhD Candidate.
E-mail: j.uribe417@uniandes.edu.co

Juliana Nieto Patiño
Universidad de los Andes Colombia - Department of Civil and Environmental Engineering. Environmental Engineering.
E-mail: j.nieto5@uniandes.edu.co

Daniel Kozak
Universidad de Buenos Aires - Habitat and Energy Research Centre CIHE / CONICET.
E-mail: daniel.kozak@fadu.uba.ar

Tom Wild
The University of Sheffield-Department of Landscape Architecture. Sheffield., United Kingdom. E-mail: t.wild@sheffield.ac.uk

Juan Pablo Rodríguez Sánchez
Universidad de los Andes Colombia - Department of Civil and Environmental Engineering. Associate Professor. E-mail: pabl-rod@uniandes.edu.co

Corresponding author: J.uribe417@uniandes.edu.co
Permanent address: Cra 1 Nº 18A- 12 Bogotá, (Colombia), postal code:11171.
Declaration of interest: none

Abstract

Nature-based Solutions (NbS) are cost-effective interventions that restore natural cycles while delivering environmental, social, and economic benefits. However, selecting appropriate biophysical evaluation methods remains a challenge, particularly in data-scarce urban contexts. Existing methodologies often lack guidance on method selection based on local data, resources, and technical constraints. To address this gap, this study develops a Decision Support Tool (DST) for selecting biophysical evaluation methods for urban NbS at neighborhood, block, or district scales. The DST is based on a systematic literature review (SLR) of 256 studies, which identified the most widely used methodologies—empirical equations, computational tools, and monitoring systems—along with key constraints such as budget, timeline, data availability, and technical expertise. Using this analysis, decision rules were established to guide method selection under different resource conditions. DST comprises three components: (i) a feasibility analysis for NbS selection, (ii) a decision-making framework for biophysical evaluation method selection, and (iii) an ecosystem services index for scenario comparison. The methodology was tested in Bogotá, Colombia, within the "El Reencuentro" urban renewal project. Results highlight the importance of urban forests in delivering ecosystem services and demonstrate the suitability of simpler methods in resource-constrained settings. By adapting biophysical evaluation approaches to local conditions, this study provides a practical framework to support NbS implementation in urban planning.

Key words:

Nature-based Solutions, regulating ecosystem services, biophysical analysis, NbS type selection.

1. Introduction

Nature-based Solutions (NbS) involve actions aimed at protecting, conserving, restoring, and sustainably managing natural or altered ecosystems—whether terrestrial, freshwater, coastal, or marine [1]. These solutions are designed to effectively and adaptively tackle social, economic, and environmental challenges while simultaneously enhancing human well-being, delivering ecosystem services, and promoting resilience and biodiversity [1–3]. Key features include multifunctionality, adaptability, and the capacity to provide regulating services such as water regulation, purification, air quality maintenance, and climate regulation [2,4–8].Common benefits of NbS implementation include improved human health and well-being, enhanced thermal comfort, energy consumption savings, noise reduction, reduced carbon footprint, avoided risk damage costs, and water consumption savings [9–13].

Over the past decade, extensive research has underscored the potential of designing and managing new ecosystems—classified as Type 3 NbS according to Eggermont's framework [14] —to address urban challenges through the ecosystem services approach in spatial planning policies and practices [3,15–19]. However, despite their growing recognition, the implementation of NbS still faces significant knowledge gaps regarding their effectiveness and long-term implications. Key challenges include assessing their benefits for well-being, analyzing synergies and trade-offs, and understanding their impacts on climate change, biodiversity, public health, and socio-economic factors [19–21]. While biodiversity is often associated with NbS, its integration into urban planning remains inconsistent, as ecological benefits are frequently assumed rather than explicitly assessed [22–24]. Addressing these gaps require structured methodologies that extend beyond ecosystem service provision to comprehensively evaluate the multiple dimensions of NbS benefits. However, this study focuses specifically on the biophysical evaluation of ecosystem services as a key approach to guiding urban planners decision-making processes.

Effectively assessing NbS ecosystem services within urban planning is a complex process that requires several critical steps both during the ex-ante planning phase and the ex-post NbS evaluation [19,25–31]. A crucial component of this process is the biophysical evaluation of urban ecosystem structure, process, and functions to quantify their impact on ecosystem service provision for subsequent benefit assessments [32].In the past three decades, biophysical evaluation of ecosystem services has been considered in Decision Support Tools (DSTs) for NbS location and selection within urban planning. A diverse range of DSTs has been developed, including spatial models, optimization tools, and ecosystem service assessment frameworks [31,33–44].

While DSTs have significantly contributed to the integration of biophysical evaluation in urban planning, their practical implementation often faces limitations related to scope, comprehensiveness, and contextual constraints. Some researchers have proposed DSTs specifically for NbS selection based on their potential to provide various ecosystem services, particularly regulating services such as climate regulation, water regulation, water purification, waste treatment, and air quality maintenance [13,37,40,44–49]. However, most existing studies are limited to specific NbS types (e.g., green infrastructure, urban green spaces, urban trees, and wetlands) and often exclude economic or social assessments. Additionally, many focus on analyzing a single ecosystem service rather than adopting a comprehensive approach. These limitations restrict the applicability of DSTs in urban planning by failing to capture the broader impact of NbS implementation, underscoring the necessity for a more comprehensive approach that integrates diverse NbS types and multiple ecosystem services. A major limitation is that is that many of the DST methodologies do not consider contextual constraints for the analysis such as data accuracy, time, technical support requirements, or project budget defaulting their replicability outside their context of development [20,50,51]. This gap highlights the need for DSTs addressing diverse NbS types and ecosystem services during biophysical evaluation and providing guidelines to select and implement feasible biophysical evaluation methodologies by urban planners.

Biophysical evaluation methodologies for NbS can be broadly classified into four categories: empirical approximations, computational tools, sampling and monitoring assessments, and mixed methods. Empirical equations, derived from observations or experiments, provide simplified assessments of ecosystem service provision [52]. Computational tools use mathematical models to describe biological, chemical, and physical phenomena within NbS processes [53]. Monitoring systems involve direct data collection on ecosystem service performance, while mixed methods integrate multiple approaches to enhance assessment accuracy [54,55]. However, the application of these methodologies —empirical equations, computational tools, and monitoring assessments—faces significant resource constraints that limit their broader applicability. Monitoring systems, for example, are often time- and cost-intensive, making them impractical for many urban planning processes [56]. Moreover, the results are frequently context-specific, depending on variables such as climatic conditions, species composition, structural attributes, and other circumstantial factors that influence ecosystem service provision [57,58]. Computational tools, while useful, require specialized expertise for model implementation, evaluation, and validation, and they depend on precise data that may not always be available. Additionally, models like i-Tree, which are parameterized for specific factors such as climate, atmospheric pollution, and vegetation, are primarily designed for the U.S. context, introducing potential biases when applied elsewhere [59,60].

The requirements in time, cost, and experience for biophysical evaluation complicate the urban planning decision-making process, particularly in zones with limited resources for urban planning analysis. While biophysical evaluations of NbS are crucial for informed decision-making, they remain particularly challenging in regions with limited data and financial resources, such as many Latin American countries. Barriers in these contexts include unclear institutional responsibilities, lack of technical expertise, financial constraints, inadequate citizen participation, absence of economic benefit valuation, and socio-economic inequities [61–63]. To address these challenges, there is a need for practical DSTs that offer easy-to-use methods to select and apply biophysical evaluation methods based on local constraints.

This study proposes an adaptable DST structured to guide urban planners decision-making on the selection and implementation biophysical evaluation of NbS ecosystem services. The primary objective is to develop a guide the selection of biophysical evaluation methodologies that function independently of resource constraints, thereby broadening analytical applicability and enabling NbS biophysical evaluation in resource-scarce settings. The research for the development of the DST include three main stages: (i) NbS feasibility analysis based on Uribe-Aguado et al. [40,64], (ii) develop a DST for selection and implementation of biophysical evaluation methodology according to the results analysis of a systematic literature review of 256 research papers conducted using Scopus

(1999–2023), and (iii) develop an Ecosystem services index to guide decision-making process based on [28,37,40,65]. To validate this approach, the methodology was implemented in an urban renewal project in Bogotá, Colombia—a highly populated and dense megacity in Latin America—as a proof of concept.

This study aims to develop a DST to assist urban planners in selecting biophysical evaluation methodologies for NbS implementation, particularly in data- and resource-constrained contexts. Unlike many existing DSTs that focus on specific NbS types or require high data accuracy and technical expertise, the tool developed in this study incorporates decision rules based on real-world resource constraints (budget, timeline, data, skills). This enhances its applicability in contexts often excluded from traditional tools, such as resource-scarce urban settings in the Global South.

2. Methodology

The methodology presented comprises three main research stages for DST development: (i) NbS feasibility analysis (ii) develop a DST for selection and implementation of biophysical evaluation methodology, and (iii) develop an Ecosystem services index to guide decision-making process. A detailed description of each research stage is provided in the following sections (see Figure 1)

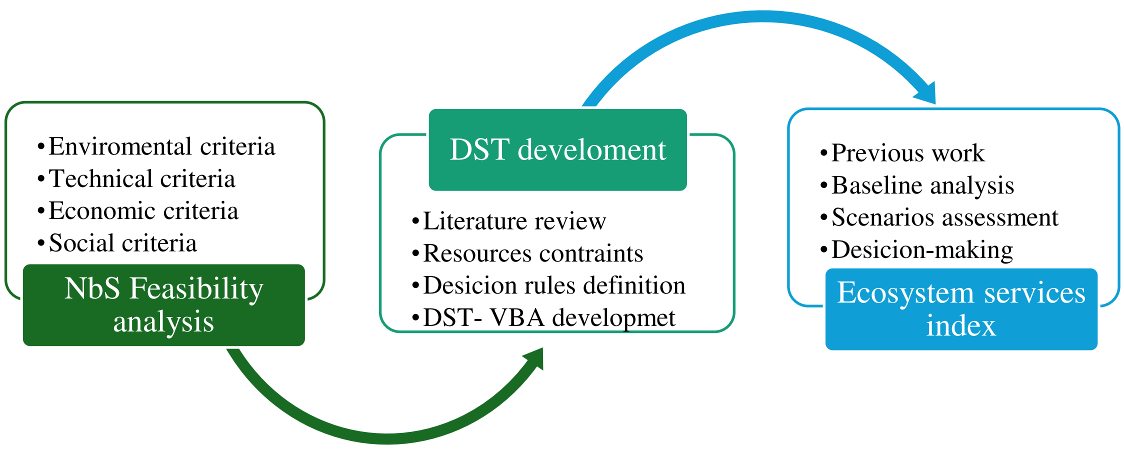

Figure 1. Three stages for DST development: i) feasibility analysis, ii) DST development, iii) ecosystem services index development

2.1 NbS feasibility analysis

In this stage, the primary objective is to integrate an NbS feasibility analysis based on previous research by Uribe-Aguado et al. [40,64]. This analysis requires input from urban planners to define the suitable NbS types for implementation within the project area. First, environmental criteria are applied to identify areas within the project zone that meet the biophysical requirements for each NbS type. Each NbS is evaluated based on specific environmental factors, including proximity to the water table, infiltration rate, slope, and its potential to address urban challenges [37,66]. These criteria ensure the feasibility and effectiveness of NbS implementation in urban settings. Following the environmental assessment, the project zone is further evaluated using technical criteria to determine the physical availability of public or private space for NbS implementation. The technical evaluation considers geometric characteristics (e.g., area, width, and length) to assess spatial feasibility, structural characteristics of the built environment (e.g., load-bearing capacity) to ensure compatibility with green infrastructure, and design parameters (e.g., tree spacing to optimize shading and air quality benefits, as well as depth and volume requirements for hydrological performance). Additionally, the assessment incorporates an analysis of public space typologies—including parks, rooftops, building facades, railway corridors, waterways, squares, sidewalks, and buffer zones— to align NbS interventions with the most appropriate urban contexts [37,66]. This integrated approach enhances the strategic implementation of NbS, ensuring their structural viability and functional effectiveness within the urban landscape.

Subsequently, the feasible NbS options are classified based on economic criteria, such as implementation costs, to generate a subset of alternatives that align with different project budget constraints. This process integrates economic feasibility as a key criterion in the overall assessment, ensuring that the selected NbS solutions are both financially viable and sustainable within the project's scope [43,67]. Finally, social criteria are evaluated through the inclusion of citizens' perspectives to identify NbS options that address priority urban challenges [67]. The potential of NbS to meet social needs is assessed based on a literature review [68–71]. The inclusion of social criteria ensures that the selected NbS interventions are not only environmentally and economically viable but also aligned with the social demands of the urban population.

The outcome of this analysis is a set of urban planning scenarios that incorporate different NbS options deemed potentially suitable for implementation. This set includes the baseline scenario or *status quo.* The final step involves selecting the NbS types that align with the prioritized ecosystem services at the site, based on criteria established by urban planners and decision-makers. This process ensures that the evaluation scenarios are adapted to the specific context of the project, enhancing their relevance and feasibility.

2.2 Develop a DST for selection and implementation of biophysical evaluation methodology

The goal of this stage is to develop a DST to select and implement a biophysical evaluation methodology. This stage was developed through an analysis of 256 articles identified via a systematic literature review (SLR) and a complementary non-systematic literature review (N-SLR) conducted using Scopus (1999–2023). The primary objective of the review was to identify the most used methods for biophysical evaluation of ecosystem services generation through NbS implementation. To achieve this, the search strategy incorporated strategic keywords (e.g., *"Infiltration basin AND ecosystem service AND urban OR Nature-based solution"),* facilitating the identification of research papers that evaluate urban ecosystem services within the context of NbS implementation. Each identified article was then classified based on the ecosystem service assessed, the type of assessment methodology (i.e., direct or indirect), and the specific biophysical evaluation method employed. A total of 256 articles were included in this phase. This classification provides a comprehensive overview of the prevailing methodologies used in NbS assessments, guiding the selection of the most appropriate methodologies for biophysical evaluation.

Then, each article was evaluated to identify potential constraints that could impact the implementation of a biophysical evaluation methodology. This assessment allowed for the identification of project management constraints, which influence the decision to implement or exclude certain methodologies. One of the primary constraints was the cost of implementation (or project Budget), particularly for methodologies involving computational tools and monitoring systems, as these often require significant financial resources [72]. Timeline constraints were also identified as a major limitation, given the periodicity and temporal variability of environmental variables and the time delay between NbS implementation and ecosystem services flow [72–74]. Data availability was another critical factor, as it directly affects the accuracy and reliability of the selected biophysical assessment methodology [72,75–77]. Lastly, team skills emerged as a key constraint, as the successful implementation of certain methodologies depends on the technical skills, multidisciplinary, and experience of the research team [72]. These constraints were adapted based on project management principles [78], ensuring that the selected assessment methodologies align with the available resources and operational feasibility within a project framework. A total of 133 articles were classified in this phase.

The information gathered from the literature review was analyzed and classified into three levels of complexity, organized according to specific project requirements. A total of 75 articles were classified in this phase. Table 1 provides an overview of this classification and its alignment with varying project needs and Figure 2 an overview of the process analysis process.

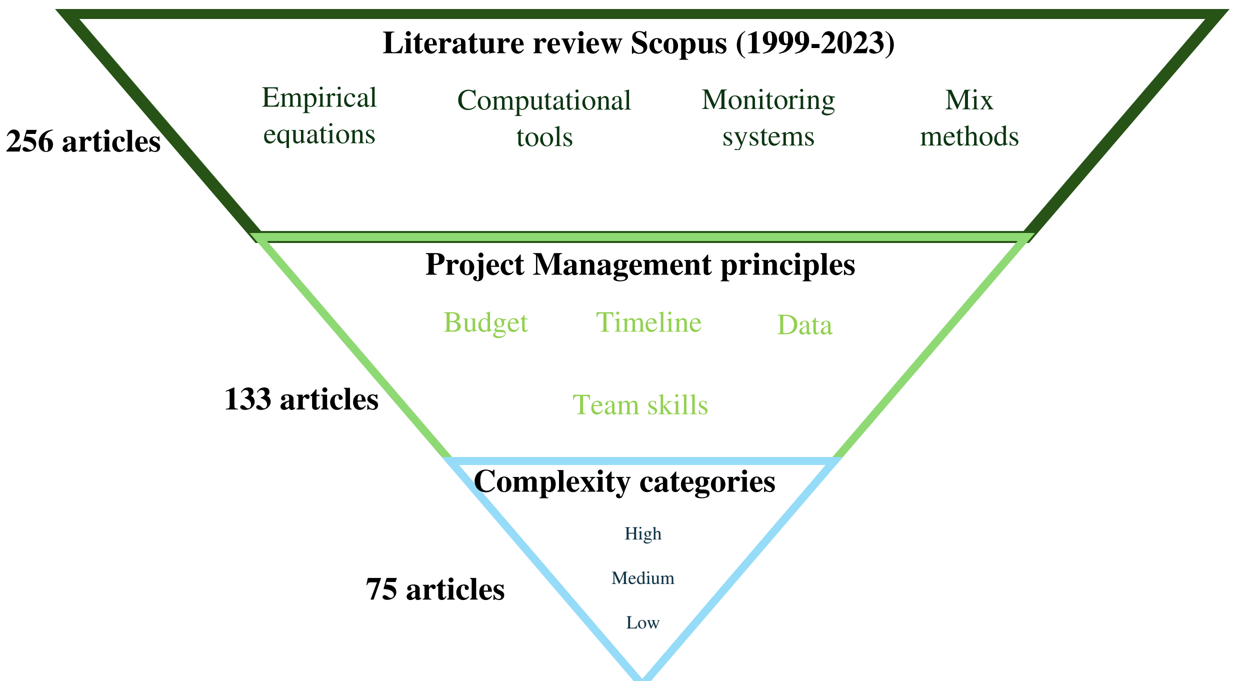

Figure 2. Literature review paper classification process according to methodologies, project management principles, and complexity categories.

Table 1. Resource level status constraints

Constraints	High level	Medium level	Low level
Budget: the approved estimate for the portfolio, program, or project, or any work breakdown structure component or schedule activity.	The project has abundant funding for the analysis of benefits. The budget can afford a sampling campaign.	The project has limited funding for the analysis but is not the most relevant constraint. The budget cannot afford a sampling campaign.	There is scarcity of funding in the project for the analysis of benefits.
Timeline: a short, fixed period in which work is to be completed.	A period of more than 10 months for the development of the analysis.	A period between 10-6 months for the development of the analysis.	A period of less than 6 months for the development of the analysis.
Data availability: a period of time when the status of a variable is recorded.	Sampled data, local official data for the site at project scale.	Local official data with mixed scales.	Local official data at city scale.
Team skills: a team that includes practitioners with	The team can develop a sampling or experimental design, statistical	The team can develop a statistical analysis had medium	The team can develop a statistical analysis had imitated or non-

Constraints	High level	Medium level	Low level
all the skills necessary to deliver valuable product increments.	analysis, and experimental analysis. In addition, the team had high quality skills in GIS software and any specialized software for the analysis.	quality skills in GIS software and any specialized software for the analysis.	quality skills in GIS software and any specialized software for the analysis.

After determining the resource-level status constraints of the project, the next step involves establishing key decision rules for selecting and implementing the most appropriate methodology. These rules were derived from the literature review, where each article was categorized based on the methods employed, their associated resource requirements, and specific constraints, including budget, timeline, data availability, and team expertise. Finally, the decision rules and the literature review were compiled into a VBA code in Excel (see detailed analysis in Supplementary Material A).

2.3 Ecosystem services index to guide decision-making process

The primary objective of the Ecosystem Services Index (IESS) is to analyze the results of the biophysical assessment to identify the NbS scenario that maximizes the provision of ecosystem services, including air quality maintenance, water regulation, and climate regulation, within the project. The construction of the index is based on previous research that recognizes the scoring process as a valuable tool for selecting urban planning scenarios for NbS implementation, considering both the demand for ecosystem services and the capacity of NbS to provide them [28,37,40,65].

After selecting and applying the biophysical evaluation methodology across the different scenarios defined in the feasibility analysis, the differences between the baseline analysis (status quo) and each evaluation scenario (Ci) are normalized (Eq. 1). These normalized values are then aggregated to generate the Integrated Ecosystem Services Score (IESS) (Eq. 2). The index can be customized by decision-makers to reflect site-specific priorities, aligning with city plans and future project objectives. The customization process assigns a value between 0 and 1 to each priority score (Pw: priority score for water regulation, Pa: priority score for air quality maintenance, and Pc: priority score for climate regulation), ensuring that their total sum equals 1. The analysis results indicate the NbS configuration scenario that best provides the necessary ecosystem services for the project.

$$\mathrm{NC_i} = \frac{\mathrm{C_i} - \mathrm{C_{imin}}}{\mathrm{C_{imax}} - \mathrm{C_{imin}}} \qquad \text{(eq. 1)}$$

Where:

NCi: normalized index benefit form ecosystem services in each scenario.
Ci: diference between the status of ecosystem services in comparison with baseline scenario.

$$\mathrm{IESS_Z} = \sum N\mathrm{C_{wr}} * \mathrm{Pw} + N\mathrm{C_{aq}} * \mathrm{Pa} + N\mathrm{C_{cr}} * \mathrm{Pc} \quad \text{(eq. 2)}$$

Where:

Z: Scenario number.
NCwr: results index preformance for water regulation.
NCaq: results index preformance for air quality maninteinance.
NCcr: results index preformance for climate regulation.

2.4 Case study

The proposed methodology was tested in the case study of “El Reencuentro,” an area located in Bogotá, Colombia (see Figure 2). This area spans 18.70 hectares and is home to 1.881 residents. It features a comprehensive road network and notable public facilities such as the Central Cemetery, the Center for Memory, Peace, and Reconciliation, and “El Renacimiento” Park, among others. This study area was chosen due to its inclusion in a future urban renewal plan that envisions the construction of a major integrated transportation hub. This hub will connect various transportation modes, including the subway, Right-most Bus Lane (RMB), and a regional tram system, significantly increasing pedestrian traffic and public space usage in the zone. However, the current conditions present significant challenges. The area surrounding the future transport station suffers from severe degradation, with a high crime rate (7.830 crimes per 100,000 inhabitants), insufficient green space (less than 10 m² per inhabitant), and insufficient public space per inhabitant (2.75 m² per inhabitant) [79]. Additionally, institutional monitoring has identified high levels of air pollution, primarily due to the concentration of nearby transport stations, a problem expected to worsen with the construction of the new transport hub [79] (see Figure 3).

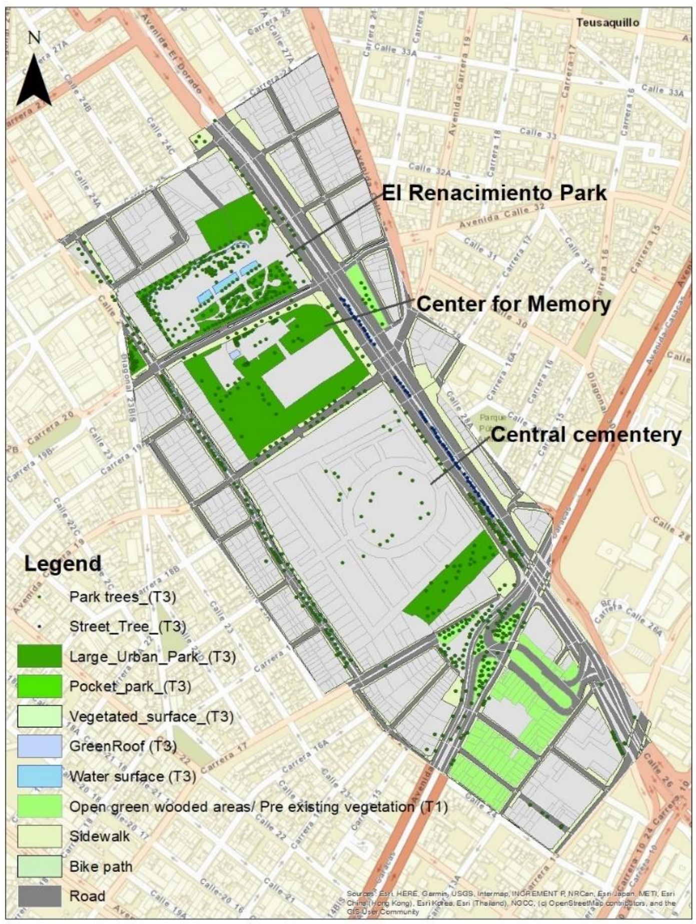

Figure 3. El Reencuentro Case study, Bogotá Colombia

The available information for the case study is presented in Supplementary material B. To enhance data inputs, a comprehensive vegetation survey was conducted in two main campaigns: the first from September to December 2023, and the second from February to March 2024. During these field campaigns, 221 trees and 38 palms were identified, while an additional 159 trees were not recorded due to site security issues or restricted private access. A total of 35 tree species were recognized, with the most common being *Ligustrum lucidum (74), Fraxinus chinensis (52), and Citharexylum subflavescens (32). For palms, only four species were identified: Phoenix canariensis (5), Yucca gigantea (6), Phoenix dactylifera (6), and Ceroxylon quindiuense (21).* Other pre-existing NbS include a small green roof, a vegetated surface within Renacimiento Park, and open green wooded areas.

3. Results

3.1 DST development for selection and implementation

Though literature review empirical equations were identified as a common methodology for assessing urban ecosystem services [80–85] , along with computational tools such as SWMM and i-Tree Hydro for evaluating water regulation services [86]. Additionally, i-Tree Eco was frequently used to assess air quality maintenance and local climate regulation [87,88]. Furthermore, monitoring systems were identified as key methodologies, with sampling designs varying depending on the ecosystem service being assessed. For water quality regulation, this assessment involves measuring NbS vegetation structure, such as Leaf Area Index and crown projection, alongside in situ meteorological data to evaluate impacts on water balance processes, including interception, infiltration, and evapotranspiration [8,56,88,89]. For air quality maintenance, the effectiveness of NbS in capturing pollutants is assessed by measuring surface concentrations of particulate matter, such as PM10, PM2.5, NOx, PAH, and metals, on the stomatal surfaces of vegetation [6,57,90–94] or through continuous air quality monitoring, comparing pollutant levels in scenarios with and without NbS implementation. For climate regulation services, analyses typically compare average temperatures before and after heat waves, measure temperature differences between shaded and sun-exposed areas, or assess temperature variations between tree-covered urban parks and areas exposed to direct sunlight [7,95,96]. Additional studies evaluate vegetation's impact on surfaces exposed to solar radiation [97,98], or quantify species' transpiration rates to better understand the role of NbS in urban cooling [58,99]. This comprehensive approach identifies empirical equations, computational simulations, and monitoring systems as biophysical evaluation methodologies that allow the analysis across multiple ecosystem services. While several existing tools such as i-Tree, SWMM, and scoring-based frameworks have been widely used to support NbS evaluations, they frequently assume the availability of high-quality data, extended timelines, and specialized technical expertise. These assumptions constrain their practical application in cities with limited resources, especially in the Global South.

Among the 256 articles reviewed, 133 explicitly addressed project management principles relevant to ecosystem services assessment. These principles included project budgets (often linked to funding declarations), analysis timelines (typically dictated by sampling processes), data availability, and the technical expertise required for assessments. The analysis revealed that 59 studies employed monitoring systems, 23 used computational tools, 15 relied on empirical equations, and 36 adopted mixed-method approaches. A total of 75 articles explicitly declared funding sources for their assessments, including project grants, scholarships, or financial support from research institutions or local authorities. Of these, 41 incorporated a monitoring process, 11 utilized computational tools, 10 employed empirical equations, and 13 applied mixed-method approaches.

Monitoring systems required high budgets and advanced or intermediate expertise, including skills in sampling design, experimental and statistical analysis, and GIS. Similarly, computational tools demand moderate to high budgets, robust data quality (e.g., official or sampled datasets), and skilled personnel for effective implementation. In contrast, empirical equations were primarily constrained by data quality, relying on accessible and reliable datasets. Notably, none of the reviewed studies conducted biophysical analyses using low-quality data. Timeline constraints varied depending on the assessment methodology. Monitoring-based assessments had an average duration of 10 months, while computational tools required between 6 and 10 months. Empirical equation-based assessments were the fastest, typically completed within 6 months (see Supplementary Material A for detailed process).

As was mentioned before, none of the reviewed studies conducted biophysical analyses using low-quality data. To address this gap, an alternative and simplified methodology, referred to as "index approximation," was proposed for scenarios where data quality is limited. The Index approximation offers a preliminary biophysical assessment. This index estimates the following ecosystem services: water regulation, based on the effects of land-use permeability changes [100]; air quality maintenance, using a simple velocity deposition model [101]; and shading, through canopy area calculations [102]. The analysis of index approximation is particularly useful in data-scarce contexts where budget constraints or team skill levels make it impractical to improve data accuracy. It provides an initial approximation of biophysical analysis for various evaluation scenarios. Results analyses were compiled as decision rules for decision-makers presented in Figure 4 and Table 2.

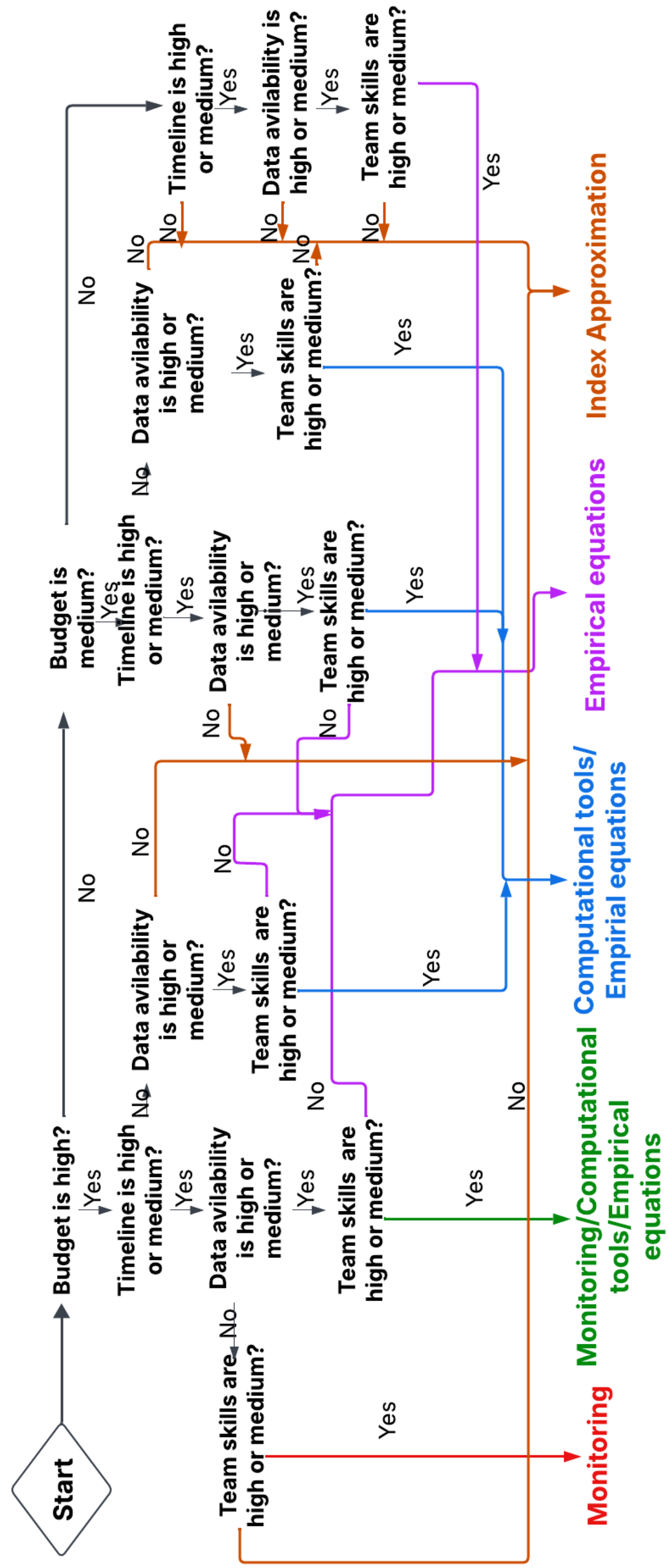

Figure 4. Decision making process diagram to select the best biophysical methodology to implement in the project.

Table 2. Decision rules for selected methodology

Method	Budget	Timeline	Data	Team skills
Monitoring	High	High Medium	Low	High Medium
Monitoring or computational tools or empirical equations	High	High Medium	High Medium	High Medium
Computational tools or empirical equations	High Medium	High Medium Low	High Medium	High Medium
Empirical equations	High Medium Low	High Medium Low	High Medium	High Medium Low
Index approximation	High Medium Low	High Medium Low	High Medium Low	Low

Then the tool developed consists of three main worksheets (see Supplementary Material C). The first worksheet, "Decision Support Tool 1," prompts users to input the status category of each resource. Based on these inputs, it generates a decision box recommending the most suitable method according to the decision rules. The results help identify the most appropriate method for the local context, whether it involves empirical equations, computational tools, or monitoring systems. The second worksheet of the Excel tool, "Implementation Guide," asks users to specify the ecosystem service they wish to assess and provides references to related articles and user manuals for certain tools, guiding the implementation process. The third worksheet of the Excel tool, "Index approximation," presents the simpler and feasible methodology for biophysical analysis approximation when it is not possible to improve data accuracy for the analysis.

The final DST consists of a three-stage methodology: (i) Definition of evaluation scenarios though a feasibility analysis (ii) Selection and implementation of biophysical evaluation scenario though VBA Excel tool (iii) Decision-making process by Ecosystem services Index (IESS). The primary objective of the first stage is to identify evaluation scenarios for NbS implementation based on technical, environmental, social, and economic criteria. In the second stage, the goal is to choose and implement a methodology to quantify a biophysical assessment methodology considering the local available resources for the analysis: project budget, timeline, and performance (data availability and team skills). In the third stage the objective is to analyze the biophysical assessment results to select the NbS scenario that promotes the generation of ecosystem services (i.e., a combination of air quality maintenance, water regulation, and climate regulation) in the project (see Figure 5).

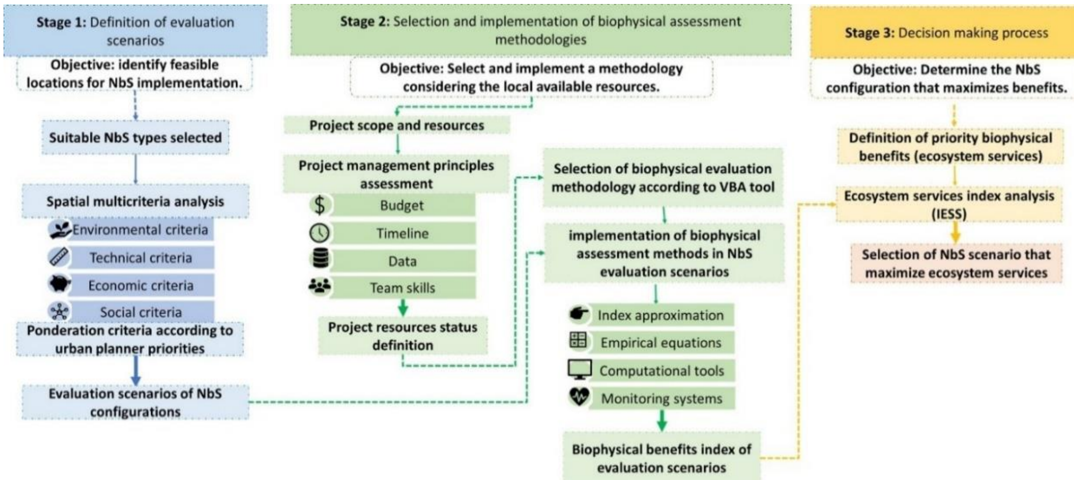

Figure 5 DST overview. Input ( ).Process(Results ( ). The process begins with Stage 1, which involves conducting a spatial multicriteria analysis that integrates environmental, technical, economic, and social criteria. Stage 2 focuses on evaluating project management principles, including budget, timeline, data availability, and team competencies. Finally, Stage 3 assesses the status of ecosystem services across different evaluation scenarios to identify the best option based on the site's priority ecosystem services.

3.2 Application to *El Reencuentro* Case study

Through the implementation of the feasibility analysis, six scenarios were defined for biophysical evaluation, each varying according to social and economic criteria. Scenario 1a was derived from a feasibility assessment considering technical and environmental criteria, with no economic constraints and without incorporating the social perception criterion criteria. Scenario 1b was defined through a feasibility assessment considering technical and environmental criteria, with an economic constraint and without incorporating the social perception criterion. Scenario 2a was defined through a feasibility assessment considering technical, environmental, social, and economic criteria, with no economic constraint. Scenario 2b was defined through a feasibility assessment considering technical, environmental, and social criteria, with an economic constraint. Scenario 3a was defined through a feasibility assessment considering technical and environmental criteria, with no economic constraint and placing the highest importance on the social perception criterion. Scenario 3b was defined through a feasibility assessment considering technical and environmental criteria, with an economic constraint and placing the highest importance on the social perception criterion. The characteristics of each scenario are presented in Supplementary Material B.

Subsequently, an evaluation of local resources was conducted to inform the selection of the most appropriate methodology for assessing project benefits, utilizing the VBA Excel tool. The project's resource classification was determined as follows**: medium budget, medium timeline allocation, medium data availability, and high team skills**. Based on these classifications, empirical equations and computational tools were selected as the primary methodologies for implementation.

The next phase involved identifying key literature guidelines and reviewing previous experiences with computational tools such as EPA-SWMM and i-Tree Eco. Additionally, a rapid approximation of the biophysical analysis was performed using the "Index Approximation" feature in the Excel tool. This preliminary assessment provides an initial quantification of the biophysical status of ecosystem services across different evaluation scenarios and serves as a foundation for further analysis. Data input requirements for Index approximation and data set-up for each model are described in Supplementary material B.

As illustrated in Figure 6, when all ecosystem services are equally weighted within the Integrated Ecosystem Services Score (IESS), Scenario 1b is identified as offering the greatest benefits, achieving an IESS score of 0.68. However, results may vary depending on the prioritization of specific ecosystem services within the IESS index. For example, Scenario 2a is the most effective for enhancing water regulation services, whereas Scenario 1b is optimal for maximizing air quality maintenance and shade provision.

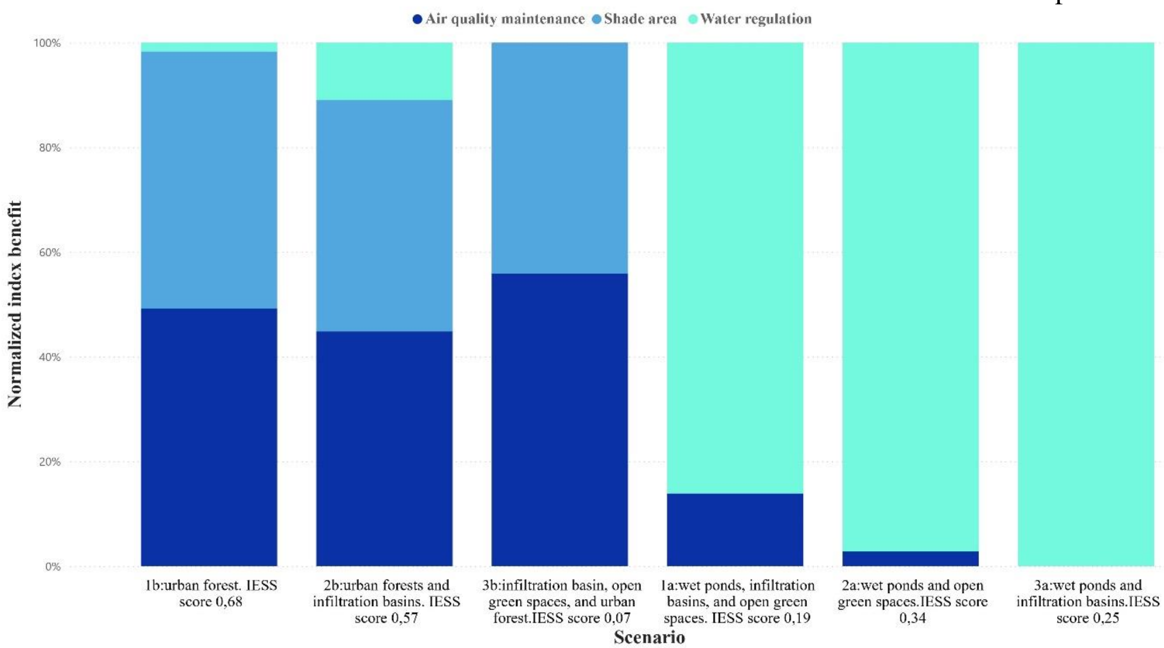

Figure 6. Normalized index benefit -Index approximation. Air quality maintenance was calculated based on the PM_{10}Kg/yr removed, the shade area was calculated as the canopy area of trees in Km^2, and water regulation as the volume of run-off saved in m^3/month.

The computational tools EPA-SWMM and i-Tree Eco were implemented according to the case study setup detailed in Supplementary Material B. The results, presented in Figure 6, indicate that under this biophysical evaluation methodology, when all ecosystem services are equally weighted within the Integrated Ecosystem Services Score (IESS), Scenarios 2b and 1b offer the greatest benefits, achieving IESS scores of 0.76 and 0.69, respectively. These scenarios emphasize urban forests as the most effective strategy for generating multiple ecosystem services. The findings highlight the crucial role of terrestrial NbS in enhancing carbon sequestration within urban contexts [103] and demonstrates the significant potential of green infrastructure strategies (e.g., urban forests, gardens, green areas, and green roofs) to improve carbon sequestration [104]. Additionally, the findings underscore the multiple benefits and co-benefits generated by urban forests in cities. Urban forests contribute to carbon sequestration both directly and indirectly: directly through CO_2 absorption via photosynthesis, and indirectly by providing cooling through shade, which reduces energy consumption and associated carbon emissions [105]. Furthermore, urban forests create synergies with other services, such as water regulation through interception and evapotranspiration, as well as air quality maintenance [106]. The potential of urban forests to provide multiple benefits is especially relevant in cities with limited budgets for NbS implementation or where NbS is not prioritized in the city plans [*55]*. This challenge is especially evident in many Latin American cities, where cost-effective and efficient solutions for climate resilience are urgently needed (see Figure 7).

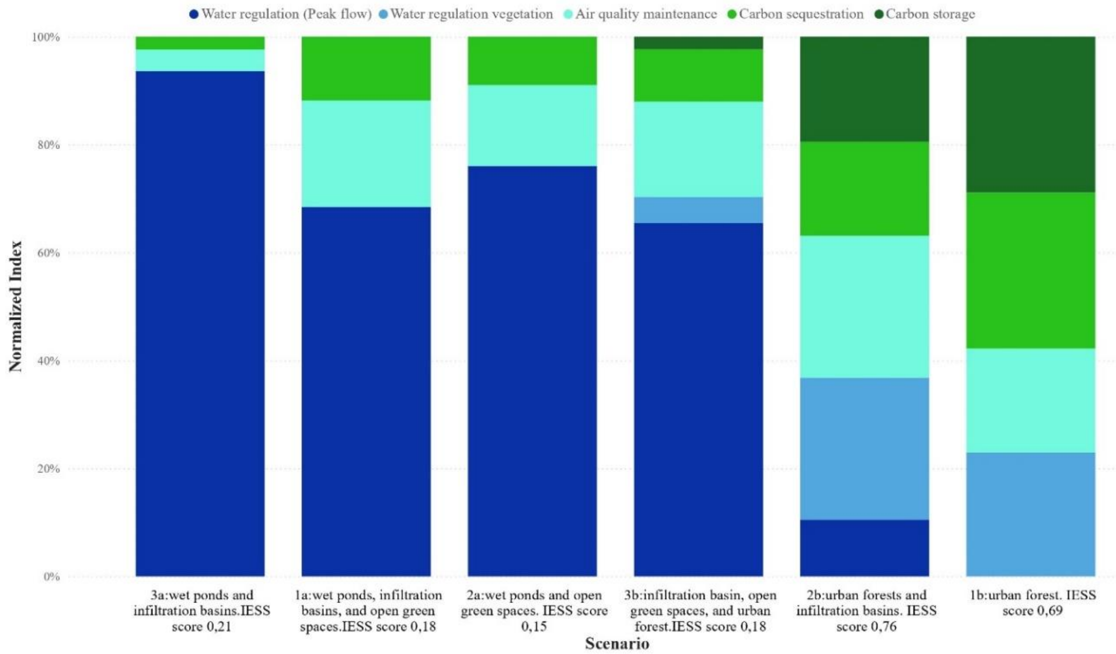

Figure 7. Normalized index benefit -Computational tools. Air quality maintenance was calculated based on the PM_{10}Kg/yr removed, carbon sequestration as CO_2Tons/yr removed. Carbon storage as CO_2Tons, water regulation associated with permeability changes as the peak flow reduction, water regulation derived by vegetation presence as the volume of run-off saved in m^3/month.

The implementation of the methodology also demonstrates that when the selection criteria prioritize more than two ecosystem services, the influence of the biophysical methodology on the analysis becomes less significant. As shown in Figure 8, the differences in percentage changes in ecosystem services provision are less pronounced when comparing index approximation to computational tools. This result support the suggestion that in contexts with high data scarcity, the best available information can still provide a reasonable estimation of changes in ecosystem services status through NbS implementation, guiding urban planning decisions effectively [20,107,108]. It indicates that the lack of data or high technical skills is not necessarily a barrier to analyzing the effectiveness of NbS implementation. Supporting the previous implementation of alternative, simpler methodologies for NbS assessment in data-scarce contexts [20,107–109]. However, these results should be used carefully when reporting effectiveness to avoid raising unrealistic expectations among stakeholders. Despite this caution, the primary value of these results lies in their potential to foster discussions with stakeholders and urban planners, thereby promoting the implementation of NbS in cities.

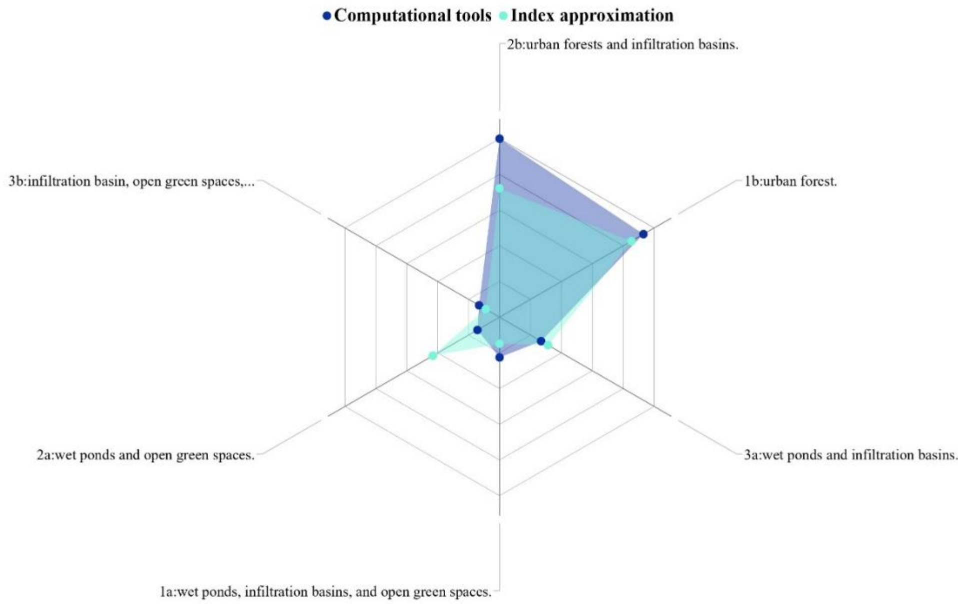

Figure 8. IESS results (score 0 to 1) in multiple prioritizations of ecosystem services according to biophysical assessment methodologies. Index approximation and computational tools.

4. Discussion

This study presents a structured DST designed to identify the most suitable methodology for assessing the implementation of NbS based on local constraints. DST integrates a feasibility analysis to evaluate the local context considering socio-economic criteria, a selection tool for biophysical assessment methodologies, and a scoring-based index to support the decision-making process. Compared to existing DSTs, which frequently presuppose ideal conditions—such as robust datasets, extended timelines, or specialized modeling skills—this study introduces a novel framework that formalizes method selection based on typical planning constraints. This distinction is particularly relevant for Global South contexts, where urban planning frequently operates under strict limitations in funding, data, and human resources. While this approach introduces key innovations that enhance the adaptability and applicability of NbS evaluations, it also presents certain limitations that should be acknowledged and addressed in future research.

The first stage of the DST follows a structured feasibility analysis similar to previous approaches but introduces two key innovations [37,40,66]. First, it systematically integrates environmental, technical, economic, and social criteria into a sequential decision-making process, ensuring that only environmentally and technically feasible NbS are considered in subsequent economic and social assessments [40,110]. This structure fills the gap by incorporating socio-economic factors into NbS DSTs [43] and addressing user preferences, a key limitation identified in other studies [44]. Additionally, hierarchical feasibility analysis enables the identification of context-specific constraints and facilitates the adaptation of NbS through spatial and technical adjustments, creating a more flexible and adaptive framework. However, two main limitations must be addressed. First, the feasibility analysis assumes static conditions for NbS in public spaces, overlooking long-term urban transformations, vegetation growth, and climate variability. This issue has already been analyzed by Lehmann et al. 2025, who emphasize the importance of incorporating a long-term perspective into NbS policy and implementations [74]. Second, and in line with the long-term view strategy of new NbS plans and policies, the economic criteria only consider implementation costs, without accounting for operation and maintenance expenses, which are critical for ensuring the long-term financial sustainability of NbS interventions [111]. Future refinements should incorporate dynamic feasibility assessments and cost-benefit analyses over extended timeframes.

The second stage introduces two significant methodological advancements. First, it implements decision rules to guide the selection of appropriate assessment methodologies based on contextual constraints, ensuring adaptability across both data-rich and data-poor environments. Second, it incorporates the Index Approximation, which provides a simplified and structured approach for estimating the biophysical impact of NbS when data accuracy is limited. These features enhance the accessibility and applicability of DST by allowing decision-makers to select the most suitable method—whether empirical equations, computational models, or monitoring systems—based on the availability of resources, expertise, and data. Despite these advantages, certain limitations remain. The primary input for DST development was a literature review of research papers. This means that other types of information, such as global analyses or guidelines (grey literature), were not considered, potentially introducing a bias—particularly in the budget and timeline categories—since academic budgets and timelines do not necessarily align with those of urban planners. However, given the available data, this approach provides the best possible approximation to real-world NbS biophysical analysis constraints. This issue has been highlighted in other studies, which identify the exclusion of grey literature as a limiting factor in the analysis [20]. Additionally, while the Index Approximation serves as a valuable alternative in data-scarce environments, it presents inherent risks of overestimating ecosystem service provision, as it does not fully account for key biophysical processes. For instance, the simpler disposition velocity method does not capture aerodynamic effects like the canyon effect in urban areas that influences air circulation and can reduce dry deposition velocity [112–114]. In addition, the shade provision is fully captured by a circle area of the crown of the trees not considering the patterns of vegetation growth or transformation that the gradual development of ecosystem services [74,115,116]. To address these challenges, future refinements should incorporate automated data validation mechanisms and hybrid approaches that integrate empirical models with GIS-based spatial analysis to improve accuracy, scalability, and reliability.

In line with previous studies [28,37,40,65], Stage 3 introduces an innovative approach to scoring-based indices, allowing for customization based on urban planning priorities and policy objectives. Unlike conventional scoring methods that apply fixed weighting criteria, this tool enables urban planners to adjust parameters according to local ecosystem service priorities, urban development plans, and stakeholder inputs [44]. As in Stage 1, this flexibility ensures that NbS prioritization aligns with municipal planning frameworks, making it a more adaptive and policy-oriented tool than traditional scoring-based indices. However, this customization process must be carefully managed to prevent biased decision-making based on subjective preferences rather than scientific and technical evidence.

4.1 Limitations and future work

Despite the limitations discussed previously, a major overarching constraint of the DST is its current inability to quantify the effect of urban biodiversity on ecosystem service provision, despite strong evidence supporting this relationship in literature. For instance, certain biodiversity attributes stand out as particularly significant. For water regulation attributes like vegetation community/habitat area are essential. Similarly, for air quality maintenance and climate regulation, factors like community/habitat age and above- and belowground biomass play a critical role [117]. At an urban level, the implementation of NbS can be seen as an opportunity to enhance urban biodiversity. NbS initiatives such as parks or urban forests often promote both ecosystem services and biodiversity [23].

Furthermore, the role of biodiversity becomes even more pronounced when economic benefits are considered. According to the *Dasgupta Review*, biodiversity ensures the harmonious interaction between Produced Capital, Natural Capital, and Human Capital, enabling nature to exhibit productivity, resilience, and adaptability [24]. Future iterations of the DST should therefore integrate biodiversity considerations as a core criterion in the feasibility analysis—especially for projects aimed at protecting or restoring urban nature. Doing so would strengthen the ecological validity of NbS evaluations and align planning frameworks with biodiversity conservation goals.

Another important limitationis a is the lack of integration of economic valuation methods beyond feasibility analysis, which could improve the analysis of NbS configurations and provide a deeper understanding of their effects on ecosystem service enhancement in urban contexts. Addressing this limitation will be crucial for future methodological improvements. The current absence of socio-economic assessments in the NbS selection process highlights a significant knowledge gap [19,118,119]. Socio-economic assessments are essential as they acknowledge potential economic trade-offs and evaluate the financial feasibility of policies supporting NbS implementation. These assessments provide a comprehensive evaluation of project costs and benefits, which can significantly influence the optimal selection of NbS through well-informed policy decisions. They also enable the comparison of natural infrastructure and services, highlighting the monetary value derived from these assessments during cost-benefit analyses [120]. Additionally, socio-economic assessments play a critical role in supporting decision-making regarding resource allocation and prioritization, compensation for losses, and the design of environmental markets [121]. A logical extension of the proposed methodology would be the inclusion of valuation approaches in the final decision-making stage, enabling urban planners to select optimal NbS scenarios not only based on ecosystem service maximization, but also on economic efficiency and social equity considerations.

5. Conclusions

This methodology has the potential to guide the selection and implementation of a proper methodology for biophysical evaluation of NbS configurations in urban contexts considering the local constraints. It also sheds light on the importance of improving data inputs and the technical skills required for ecosystem service assessments. Notably, a thorough understanding of the biophysical effects of each NbS typology can reduce the reliance on complex assessment methodologies, making the process more accessible. However, enhancing the quality of data inputs remains critical for making robust and actionable recommendations during the NbS selection process.

The methodology highlights that a lack of data or technical skills should not be used as an argument to avoid conducting a biophysical evaluation of ecosystem services provided by NbS. The findings suggest that even in the absence of extensive data or advanced technical expertise, it is possible to assess the effectiveness of NbS implementation. This supports the use of alternative, empirical, or simplified methods in data-scarce contexts. Nevertheless, caution should be exercised when interpreting and communicating these results, as they may unintentionally create unrealistic expectations among stakeholders. Despite this limitation, the results have significant value in fostering dialogue with stakeholders and urban planners, promoting the adoption of NbS in urban areas. In addition, unlike prior tools that offer limited guidance for constrained environments, this DST formalizes resource-based decision-making and extends the analytical capacity of urban planners regardless of data or technical limitations.

The methodology was successfully applied to the case study in Bogotá, underlining the value of urban forests in delivering multiple regulating ecosystem services in local contexts. Finally, it is important to note that sampling and monitoring alternatives were excluded from this analysis due to high resource requirements (e.g., time and budget). A future iteration of this methodology could incorporate such approaches to explore their impact on ecosystem service quantification and further refine the assessment process.

6. References

[1] The United Nations Environment Assembly. Nature-based Solutions for Climate Resilient Cities: Perspectives and experiences from Latin America. United Nations Environment Programme; 2023.

[2] Nature-based solutions - European Commission 2023. https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en (accessed July 30, 2024).

[3] Cohen-Shacham E, Walters G, Maginnis S, Janzen C. Nature-based Solutions to address global societal challenges. 2016. https://doi.org/10.2305/IUCN.CH.2016.13.en.

[4] Pauleit S, Zölch T, Hansen R, Randrup TB, Konijnendijk van den Bosch C. Nature-Based Solutions and Climate Change – Four Shades of Green. In: Kabisch N, Korn H, Stadler J, Bonn A, editors. Nat.-Based Solut. Clim. Change Adapt. Urban Areas Link. Sci. Policy Pract., Cham: Springer International Publishing; 2017, p. 29–49. https://doi.org/10.1007/978-3-319-56091-5_3.

[5] Estándar Global de la UICN para soluciones basadas en la naturaleza. UICN. 2020. n.d.

[6] Zafra-Mejía C, Suárez-López J, Rondón-Quintana H. Analysis of Particulate Matter Concentration Intercepted by Trees of a Latin-American Megacity. Forests 2021;12:723. https://doi.org/10.3390/f12060723.

[7] Sanusi R, Livesley SJ. London Plane trees (*Platanus* x *acerifolia*) before, during and after a heatwave: Losing leaves means less cooling benefit. Urban For Urban Green 2020;54:126746. https://doi.org/10.1016/j.ufug.2020.126746.

[8] Selbig WR, Loheide SP, Shuster W, Scharenbroch BC, Coville RC, Kruegler J, et al. Quantifying the stormwater runoff volume reduction benefits of urban street tree canopy. Sci Total Environ 2022;806:151296. https://doi.org/10.1016/j.scitotenv.2021.151296.

[9] Tsai W-L, Yngve L, Zhou Y, Beyer KMM, Bersch A, Malecki KM, et al. Street-level neighborhood greenery linked to active transportation: A case study in Milwaukee and Green Bay, WI, USA. Landsc Urban Plan 2019;191:103619. https://doi.org/10.1016/j.landurbplan.2019.103619.

[10] Venter ZS, Krog NH, Barton DN. Linking green infrastructure to urban heat and human health risk mitigation in Oslo, Norway. Sci Total Environ 2020;709:136193. https://doi.org/10.1016/j.scitotenv.2019.136193.

[11] Singh A, Singh H, Singh JS. Plant Diversity in Cities:Call for Assessment and Conservation. Curr Sci 2018;115:428–35. https://doi.org/10.18520/cs/v115/i3/428-435.

[12] Ow LF, Ghosh S. Urban cities and road traffic noise: Reduction through vegetation. Appl Acoust 2017;120:15–20. https://doi.org/10.1016/j.apacoust.2017.01.007.

[13] Fraga JPR, Okumura CK, Guimarães LF, Arruda RN de, Becker BR, de Oliveira AKB, et al. Cost-benefit analysis of sustainable drainage systems considering ecosystems services benefits: case study of canal do mangue watershed in Rio de Janeiro city, Brazil. Clean Technol Environ Policy 2022;24:695–712. https://doi.org/10.1007/s10098-021-02221-w.

[14] Eggermont H, Balian E, Azevedo M, Beumer V, Brodin T, Claudet J, et al. Nature-based Solutions: New Influence for Environmental Management and Research in Europe. Gaia Okologische Perspekt Nat- Geistes- Wirtsch 2015;24:243–8. https://doi.org/10.14512/gaia.24.4.9.
[15] Castellar JAC, Popartan LA, Pueyo-Ros J, Atanasova N, Langergraber G, Säumel I, et al. Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. Sci Total Environ 2021;779:146237. https://doi.org/10.1016/j.scitotenv.2021.146237.
[16] Dushkova D, Haase D. Methodology for development of a data and knowledge base for learning from existing nature-based solutions in Europe: The CONNECTING Nature project. MethodsX 2020;7:101096. https://doi.org/10.1016/j.mex.2020.101096.
[17] Langergraber G, Castellar JAC, Pucher B, Baganz GFM, Milosevic D, Andreucci M-B, et al. A Framework for Addressing Circularity Challenges in Cities with Nature-Based Solutions. Water 2021;13:2355. https://doi.org/10.3390/w13172355.
[18] Babí Almenar J, Elliot T, Rugani B, Philippe B, Navarrete Gutierrez T, Sonnemann G, et al. Nexus between nature-based solutions, ecosystem services and urban challenges. Land Use Policy 2021;100:104898. https://doi.org/10.1016/j.landusepol.2020.104898.
[19] Raymond CM, Frantzeskaki N, Kabisch N, Berry P, Breil M, Nita MR, et al. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. Environ Sci Policy 2017;77:15–24. https://doi.org/10.1016/j.envsci.2017.07.008.
[20] Wild T, Baptista M, Wilker J, Kanai JM, Giusti M, Henderson H, et al. Valuation of urban nature-based solutions in Latin American and European cities. Urban For Urban Green 2024;91:128162. https://doi.org/10.1016/j.ufug.2023.128162.
[21] European Commission. Directorate General for Research and Innovation. Evaluating the impact of nature-based solutions: appendix of methods. LU: Publications Office; 2021.
[22] Lepczyk CA, Aronson MFJ, Evans KL, Goddard MA, Lerman SB, MacIvor JS. Biodiversity in the City: Fundamental Questions for Understanding the Ecology of Urban Green Spaces for Biodiversity Conservation. BioScience 2017;67:799–807. https://doi.org/10.1093/biosci/bix079.
[23] Langemeyer J, Gómez-Baggethun E. Urban biodiversity and ecosystem services. Urban Biodivers., Routledge; 2017.
[24] Final Report - The Economics of Biodiversity: The Dasgupta Review. GOVUK 2021. https://www.gov.uk/government/publications/final-report-the-economics-of-biodiversity-the-dasgupta-review (accessed December 3, 2024).
[25] Beceiro P, Brito RS, Galvão A. Assessment of the contribution of Nature-Based Solutions (NBS) to urban resilience: application to the case study of Porto. Ecol Eng 2022;175:106489. https://doi.org/10.1016/j.ecoleng.2021.106489.
[26] Calliari E, Staccione A, Mysiak J. An assessment framework for climate-proof nature-based solutions. Sci Total Environ 2019;656:691–700. https://doi.org/10.1016/j.scitotenv.2018.11.341.
[27] Liquete C, Udias A, Conte G, Grizzetti B, Masi F. Integrated valuation of a nature-based solution for water pollution control. Highlighting hidden benefits. Ecosyst Serv 2016;22:392–401. https://doi.org/10.1016/j.ecoser.2016.09.011.
[28] Croeser T, Garrard G, Sharma R, Ossola A, Bekessy S. Choosing the right nature-based solutions to meet diverse urban challenges. Urban For Urban Green 2021;65:127337. https://doi.org/10.1016/j.ufug.2021.127337.
[29] Kuller M, Farrelly M, Marthanty DR, Deletic A, Bach PM. Planning support systems for strategic implementation of nature-based solutions in the global south: Current role and

future potential in Indonesia. Cities 2022;126:103693. https://doi.org/10.1016/j.cities.2022.103693.
[30] Kumar P, Debele SE, Sahani J, Aragão L, Barisani F, Basu B, et al. Towards an operationalisation of nature-based solutions for natural hazards. Sci Total Environ 2020;731:138855. https://doi.org/10.1016/j.scitotenv.2020.138855.
[31] Beceiro P, Brito RS, Galvão A. The Contribution of NBS to Urban Resilience in Stormwater Management and Control: A Framework with Stakeholder Validation. Sustainability 2020;12:2537. https://doi.org/10.3390/su12062537.
[32] Semeraro T, Buccolieri R. Editorial: “Urban Ecosystem Service Assessments.” Front Environ Sci 2022;10. https://doi.org/10.3389/fenvs.2022.825002.
[33] García AM, Santé I, Loureiro X, Miranda D. Green infrastructure spatial planning considering ecosystem services assessment and trade-off analysis. Application at landscape scale in Galicia region (NW Spain). Ecosyst Serv 2020;43:101115. https://doi.org/10.1016/j.ecoser.2020.101115.
[34] Langemeyer J, Wedgwood D, McPhearson T, Baró F, Madsen AL, Barton DN. Creating urban green infrastructure where it is needed – A spatial ecosystem service-based decision analysis of green roofs in Barcelona. Sci Total Environ 2020;707:135487. https://doi.org/10.1016/j.scitotenv.2019.135487.
[35] Torres MN, Fontecha JE, Walteros JL, Zhu Z, Ahmed Z, Rodríguez JP, et al. City-scale optimal location planning of Green Infrastructure using piece-wise linear interpolation and exact optimization methods. J Hydrol 2021;601:126540. https://doi.org/10.1016/j.jhydrol.2021.126540.
[36] Bach PM, McCarthy DT, Urich C, Sitzenfrei R, Kleidorfer M, Rauch W, et al. A planning algorithm for quantifying decentralised water management opportunities in urban environments. Water Sci Technol J Int Assoc Water Pollut Res 2013;68:1857–65. https://doi.org/10.2166/wst.2013.437.
[37] Jiménez-Ariza SL, Rey CV, Rodríguez JP, Guzmán-Ramírez M. Multi-Criteria Decision Analysis Inputs for Planning the Implementation of Nature-based Solutions in Urban Contexts. ACE Archit City Environ 2023;18.
[38] Sebti A, Fuamba M, Bennis S. Optimization Model for BMP Selection and Placement in a Combined Sewer. J Water Resour Plan Manag 2016;142:04015068. https://doi.org/10.1061/(ASCE)WR.1943-5452.0000620.
[39] Raei E, Reza Alizadeh M, Reza Nikoo M, Adamowski J. Multi-objective decision-making for green infrastructure planning (LID-BMPs) in urban storm water management under uncertainty. J Hydrol 2019;579:124091. https://doi.org/10.1016/j.jhydrol.2019.124091.
[40] Uribe-Aguado J, Jiménez-Ariza SL, Torres MN, Bernal NA, Giraldo-González MM, Rodríguez JP. A SUDS Planning Decision Support Tool to Maximize Ecosystem Services. Sustainability 2022;14:4560. https://doi.org/10.3390/su14084560.
[41] Ranta E, Vidal-Abarca MR, Calapez AR, Feio MJ. Urban stream assessment system (UsAs): An integrative tool to assess biodiversity, ecosystem functions and services. Ecol Indic 2021;121:106980. https://doi.org/10.1016/j.ecolind.2020.106980.
[42] Possantti I, Marques G. A modelling framework for nature-based solutions expansion planning considering the benefits to downstream urban water users. Environ Model Softw 2022;152:105381. https://doi.org/10.1016/j.envsoft.2022.105381.
[43] Sahay S. Nature-based solutions as urban adaptation to climate risk: Framework for economic evaluation as decision support tool. Sustain Cities Soc 2025;118:106037. https://doi.org/10.1016/j.scs.2024.106037.

[44] Babí Almenar J, Petucco C, Navarrete Gutiérrez T, Chion L, Rugani B. Assessing Net Environmental and Economic Impacts of Urban Forests: An Online Decision Support Tool. Land 2023;12:70. https://doi.org/10.3390/land12010070.
[45] Engström R, Howells M, Mörtberg U, Destouni G. Multi-functionality of nature-based and other urban sustainability solutions: New York City study. Land Degrad Dev 2018;29:3653–62. https://doi.org/10.1002/ldr.3113.
[46] Epelde L, Mendizabal M, Gutiérrez L, Artetxe A, Garbisu C, Feliu E. Quantification of the environmental effectiveness of nature-based solutions for increasing the resilience of cities under climate change. Urban For Urban Green 2022;67:127433. https://doi.org/10.1016/j.ufug.2021.127433.
[47] Kourtis IM, Bellos V, Kopsiaftis G, Psiloglou B, Tsihrintzis VA. Methodology for holistic assessment of grey-green flood mitigation measures for climate change adaptation in urban basins. J Hydrol 2021;603:126885. https://doi.org/10.1016/j.jhydrol.2021.126885.
[48] Alves A, Vojinovic Z, Kapelan Z, Sanchez A, Gersonius B. Exploring trade-offs among the multiple benefits of green-blue-grey infrastructure for urban flood mitigation. Sci Total Environ 2020;703:134980. https://doi.org/10.1016/j.scitotenv.2019.134980.
[49] Speak AF, Montagnani L, Solly H, Wellstein C, Zerbe S. The impact of different tree planting strategies on ecosystem services and disservices in the piazzas of a northern Italian city. Urban Ecosyst 2022;25:355–66. https://doi.org/10.1007/s11252-021-01158-8.
[50] Wessels N, Sitas N, O'Farrell P, Esler KJ. Inclusion of ecosystem services in the management of municipal natural open space systems. People Nat 2024;6:301–20. https://doi.org/10.1002/pan3.10572.
[51] Ouyang X, Luo X. Models for Assessing Urban Ecosystem Services: Status and Outlooks. Sustainability 2022;14:4725. https://doi.org/10.3390/su14084725.
[52] Buckingham, E. Model Experiments and the forms of Empirical equations.Wasington D.C. n.d.
[53] Wastewater Treatment Process Modeling, MOP31. 2nd Edition. McGraw-Hill Education; 2014.
[54] BD S, W E, SEM M, GM W, GR G, JF B, et al. Effective ecosystem monitoring requires a multi-scaled approach. Biol Rev Camb Philos Soc 2020;95:1706–19. https://doi.org/10.1111/brv.12636.
[55] Dunford R, Harrison P, Smith A, Dick J, Barton DN, Martin-Lopez B, et al. Integrating methods for ecosystem service assessment: Experiences from real world situations. Ecosyst Serv 2018;29:499–514. https://doi.org/10.1016/j.ecoser.2017.10.014.
[56] Stratópoulos LMF, Duthweiler S, Häberle K-H, Pauleit S. Effect of native habitat on the cooling ability of six nursery-grown tree species and cultivars for future roadside plantings. Urban For Urban Green 2018;30:37–45. https://doi.org/10.1016/j.ufug.2018.01.011.
[57] Chen G, Lin L, Hu Y, Zhang Y, Ma K. Net particulate matter removal ability and efficiency of ten plant species in Beijing. Urban For Urban Green 2021;63:127230. https://doi.org/10.1016/j.ufug.2021.127230.
[58] Gillner S, Vogt J, Tharang A, Dettmann S, Roloff A. Role of street trees in mitigating effects of heat and drought at highly sealed urban sites. Landsc Urban Plan 2015;143:33–42. https://doi.org/10.1016/j.landurbplan.2015.06.005.
[59] Ersoy Tonyaloğlu E, Atak BK. Impact of land cover change on urban tree cover and potential regulating ecosystem services: the case of Aydın/Turkey. Environ Monit Assess 2021;193:736. https://doi.org/10.1007/s10661-021-09531-y.

[60] Berland A. Urban tree growth models for two nearby cities show notable differences. Urban Ecosyst 2020;23:1253–61. https://doi.org/10.1007/s11252-020-01015-0.
[61] Masson-Delmotte V, Zhai P, Pirani A, Connors SL, Péan C, Berger S, et al., editors. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press; 2021. https://doi.org/10.1017/9781009157896.
[62] Lafortezza R, Giannico V. Combining high-resolution images and LiDAR data to model ecosystem services perception in compact urban systems. Ecol Indic 2019;96:87–98. https://doi.org/10.1016/j.ecolind.2017.05.014.
[63] Zheng S, Yang S, Ma M, Dong J, Han B, Wang J. Linking cultural ecosystem service and urban ecological-space planning for a sustainable city: Case study of the core areas of Beijing under the context of urban relieving and renewal. Sustain Cities Soc 2023;89:104292. https://doi.org/10.1016/j.scs.2022.104292.
[64] Uribe-Aguado J, Giraldo-Gonzalez MM, Biesaga M, Domaradzka A, Baki S, Kazantzi A, et al. (Publication process) A feasibility methodology for selecting and locating urban Nature-based solutions (NbS) considering socio-economic criteria. Ecol Indic 2025.
[65] Longato D, Cortinovis C, Balzan M, Geneletti D. A method to prioritize and allocate nature-based solutions in urban areas based on ecosystem service demand. Landsc Urban Plan 2023;235:104743. https://doi.org/10.1016/j.landurbplan.2023.104743.
[66] Alves RA, Santos MM dos, Rudke AP, Francisquetti Venturin PR, Martins JA. Site selection for nature-based solutions for stormwater management in urban areas: An approach combining GIS and multi-criteria analysis. J Environ Manage 2024;359:120999. https://doi.org/10.1016/j.jenvman.2024.120999.
[67] Aghaloo K, Sharifi A. Integrated spatial prioritization of urban nature-based solutions for climate adaptation, mitigation, and justice. Int J Sustain Dev World Ecol n.d.;0:1–18. https://doi.org/10.1080/13504509.2024.2424988.
[68] Castellar JAC, Popartan LA, Pueyo-Ros J, Atanasova N, Langergraber G, Säumel I, et al. Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. Sci Total Environ 2021;779:146237. https://doi.org/10.1016/j.scitotenv.2021.146237.
[69] Jim CY, Hui LC. Offering green roofs in a compact city: Benefits and landscape preferences of socio-demographic cohorts. Appl Geogr 2022;145:102733. https://doi.org/10.1016/j.apgeog.2022.102733.
[70] Łaszkiewicz E, Kronenberg J, Mohamed AA, Roitsch D, De Vreese R. Who does not use urban green spaces and why? Insights from a comparative study of thirty-three European countries. Landsc Urban Plan 2023;239:104866. https://doi.org/10.1016/j.landurbplan.2023.104866.
[71] Amegah AK, Yeboah K, Owusu V, Afriyie L, Kyere-Gyeabour E, Appiah DC, et al. Socio-demographic and neighbourhood factors influencing urban green space use and development at home: A population-based survey in Accra, Ghana. PLOS ONE 2023;18:e0286332. https://doi.org/10.1371/journal.pone.0286332.
[72] van Lierop M, Dobbs C, Flores C, van der Jagt A, Skiba A, Locosselli GM, et al. Monitoring and assessment in the context of governance of nature-based solutions. Shared challenges and opportunities in CELAC and EU cities. Nat-Based Solut 2024;6:100170. https://doi.org/10.1016/j.nbsj.2024.100170.

[73] Adamowicz W, Calderon-Etter L, Entem A, Fenichel EP, Hall JS, Lloyd-Smith P, et al. Assessing ecological infrastructure investments. Proc Natl Acad Sci 2019;116:5254–61. https://doi.org/10.1073/pnas.1802883116.
[74] Lehmann I, Grosinger J, Bauer S, Rodríguez de Francisco JC, Negacz K, Hein J. Time in and for nature-based solutions. No quick fix solutions for complex ecological and social processes. Nat-Based Solut 2025;7:100219. https://doi.org/10.1016/j.nbsj.2025.100219.
[75] (PDF) Methodologies to Assess and Map the Biophysical Effectiveness of Nature Based Solutions. ResearchGate, 2024. https://doi.org/10.1007/978-3-031-25308-9_4.
[76] Chappin MMH, Punt MJ, Toxopeus HS, van Tilburg N, de Jongh CL, Runhaar HAC, et al. How can networks address barriers to nature-based solutions? The case of agriculture and construction in the Netherlands. Landsc Urban Plan 2024;251:105147. https://doi.org/10.1016/j.landurbplan.2024.105147.
[77] Kumar P, Debele SE, Sahani J, Rawat N, Marti-Cardona B, Alfieri SM, et al. Nature-based solutions efficiency evaluation against natural hazards: Modelling methods, advantages and limitations. Sci Total Environ 2021;784:147058. https://doi.org/10.1016/j.scitotenv.2021.147058.
[78] Project Management: A Systems Approach to Planning, Scheduling, and Controlling, 13th Edition | Wiley n.d. https://www.wiley.com/en-us/Project+Management%3A+A+Systems+Approach+to+Planning%2C+Scheduling%2C+and+Controlling%2C+13th+Edition-p-9781119805373 (accessed July 30, 2024).
[79] Planes | Secretaría Distrital de Planeación n.d. https://www.sdp.gov.co/gestion-territorial/planes-parciales-de-renovacion-urbana/planes (accessed July 30, 2024).
[80] Vico G, Revelli R, Porporato A. Ecohydrology of street trees: design and irrigation requirements for sustainable water use. Ecohydrology 2014;7:508–23. https://doi.org/10.1002/eco.1369.
[81] Jim CY, Chen WY. Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). J Environ Manage 2008;88:665–76. https://doi.org/10.1016/j.jenvman.2007.03.035.
[82] Matos P, Vieira J, Rocha B, Branquinho C, Pinho P. Modeling the provision of air-quality regulation ecosystem service provided by urban green spaces using lichens as ecological indicators. Sci Total Environ 2019;665:521–30. https://doi.org/10.1016/j.scitotenv.2019.02.023.
[83] Estimating the cooling capacity of green infrastructures to support urban planning - ScienceDirect n.d. https://www.sciencedirect.com/science/article/abs/pii/S2212041617301171?fr=RR-2&ref=pdf_download&rr=8e929ff61ae4d9b1 (accessed November 27, 2024).
[84] Meshram SG, Ilderomi AR, Sepehri M, Jahanbakhshi F, Kiani-Harchegani M, Ghahramani A, et al. Impact of roof rain water harvesting of runoff capture and household consumption. Environ Sci Pollut Res 2021;28:49529–40. https://doi.org/10.1007/s11356-021-14098-9.
[85] Prenner F, Pucher B, Zluwa I, Pitha U, Langergraber G. Rainwater Use for Vertical Greenery Systems: Development of a Conceptual Model for a Better Understanding of Processes and Influencing Factors. Water 2021;13:1860. https://doi.org/10.3390/w13131860.
[86] Yang S, Ruangpan L, Torres AS, Vojinovic Z. Multi-objective Optimisation Framework for Assessment of Trade-Offs between Benefits and Co-benefits of Nature-based Solutions. Water Resour Manag 2023;37:2325–45. https://doi.org/10.1007/s11269-023-03470-8.

[87] Yousofpour Y, Abolhassani L, Hirabayashi S, Burgess D, Sabouhi Sabouni M, Daneshvarkakhki M. Ecosystem services and economic values provided by urban park trees in the air polluted city of Mashhad. Sustain Cities Soc 2024;101:105110. https://doi.org/10.1016/j.scs.2023.105110.
[88] Elliott RM, Adkins ER, Culligan PJ, Palmer MI. Stormwater infiltration capacity of street tree pits: Quantifying the influence of different design and management strategies in New York City. Ecol Eng 2018;111:157–66. https://doi.org/10.1016/j.ecoleng.2017.12.003.
[89] Peters EB, Hiller RV, McFadden JP. Seasonal contributions of vegetation types to suburban evapotranspiration. J Geophys Res Biogeosciences 2011;116. https://doi.org/10.1029/2010JG001463.
[90] Muhammad S, Wuyts K, Samson R. Immobilized atmospheric particulate matter on leaves of 96 urban plant species. Environ Sci Pollut Res 2020;27:36920–38. https://doi.org/10.1007/s11356-020-09246-6.
[91] Ugolini F, Tognetti R, Raschi A, Bacci L. *Quercus ilex* L. as bioaccumulator for heavy metals in urban areas: Effectiveness of leaf washing with distilled water and considerations on the trees distance from traffic. Urban For Urban Green 2013;12:576–84. https://doi.org/10.1016/j.ufug.2013.05.007.
[92] Tepanosyan G, Baldacchini C, Sahakyan L. Revealing Soil and Tree Leaves Deposited Particulate Matter PTE Relationship and Potential Sources in Urban Environment. Int J Environ Res Public Health 2021;18:10412. https://doi.org/10.3390/ijerph181910412.
[93] Gong C, Xian C, Cui B, He G, Wei M, Zhang Z, et al. Estimating NOx removal capacity of urban trees using stable isotope method: A case study of Beijing, China. Environ Pollut 2021;290:118004. https://doi.org/10.1016/j.envpol.2021.118004.
[94] Papa S, Bartoli G, Nacca F, D'Abrosca B, Cembrola E, Pellegrino A, et al. Trace metals, peroxidase activity, PAHs contents and ecophysiological changes in *Quercus ilex* leaves in the urban area of Caserta (Italy). J Environ Manage 2012;113:501–9. https://doi.org/10.1016/j.jenvman.2012.05.032.
[95] Stanley CH, Helletsgruber C, Hof A. Mutual Influences of Urban Microclimate and Urban Trees: An Investigation of Phenology and Cooling Capacity. Forests 2019;10:533. https://doi.org/10.3390/f10070533.
[96] Georgi NJ, Zafiriadis K. The impact of park trees on microclimate in urban areas. Urban Ecosyst 2006;9:195–209. https://doi.org/10.1007/s11252-006-8590-9.
[97] Balogun AA, Morakinyo TE, Adegun OB. Effect of tree-shading on energy demand of two similar buildings. Energy Build 2014;81:305–15. https://doi.org/10.1016/j.enbuild.2014.05.046.
[98] Berry R, Livesley SJ, Aye L. Tree canopy shade impacts on solar irradiance received by building walls and their surface temperature. Build Environ 2013;69:91–100. https://doi.org/10.1016/j.buildenv.2013.07.009.
[99] Zhang C, Stratopoulos LMF, Pretzsch H, Rötzer T. How Do Tilia cordata Greenspire Trees Cope with Drought Stress Regarding Their Biomass Allocation and Ecosystem Services? Forests 2019;10:676. https://doi.org/10.3390/f10080676.
[100] Nachshon U, Netzer L, Livshitz Y. Land cover properties and rain water harvesting in urban environments. Sustain Cities Soc 2016;27:398–406. https://doi.org/10.1016/j.scs.2016.08.008.
[101] Escobedo FJ, Clerici N, Staudhammer CL, Corzo GT. Socio-ecological dynamics and inequality in Bogotá, Colombia's public urban forests and their ecosystem services. Urban For Urban Green 2015;14:1040–53. https://doi.org/10.1016/j.ufug.2015.09.011.

[102] Horváthová E, Badura T, Duchková H. The value of the shading function of urban trees: A replacement cost approach. Urban For Urban Green 2021;62:127166. https://doi.org/10.1016/j.ufug.2021.127166.
[103] Pereira P, Wang F, Inacio M, Kalinauskas M, Bogdzevič K, Bogunovic I, et al. Nature-based solutions for carbon sequestration in urban environments. Curr Opin Environ Sci Health 2024;37:100536. https://doi.org/10.1016/j.coesh.2024.100536.
[104] Rachid L, Elmostafa A, Mehdi M, Hassan R. Assessing carbon storage and sequestration benefits of urban greening in Nador City, Morocco, utilizing GIS and the InVEST model. Sustain Futur 2024;7:100171. https://doi.org/10.1016/j.sftr.2024.100171.
[105] Bherwani H, Banerji T, Menon R. Role and value of urban forests in carbon sequestration: review and assessment in Indian context. Environ Dev Sustain 2024;26:603–26. https://doi.org/10.1007/s10668-022-02725-5.
[106] Babí Almenar J, Petucco C, Sonnemann G, Geneletti D, Elliot T, Rugani B. Modelling the net environmental and economic impacts of urban nature-based solutions by combining ecosystem services, system dynamics and life cycle thinking: An application to urban forests. Ecosyst Serv 2023;60:101506. https://doi.org/10.1016/j.ecoser.2022.101506.
[107] Balzan M, Zulian G, Maes J, Borg M. Assessing urban ecosystem services to prioritise nature-based solutions in a high-density urban area. Nat-Based Solut 2021;1:100007. https://doi.org/10.1016/j.nbsj.2021.100007.
[108] Alves A, van Opstal C, Keijzer N, Sutton N, Chen W-S. Planning the multifunctionality of nature-based solutions in urban spaces. Cities 2024;146:104751. https://doi.org/10.1016/j.cities.2023.104751.
[109] Escobedo FJ, Clerici N, Staudhammer CL, Corzo GT. Socio-ecological dynamics and inequality in Bogotá, Colombia's public urban forests and their ecosystem services. Urban For Urban Green 2015;14:1040–53. https://doi.org/10.1016/j.ufug.2015.09.011.
[110] Basco-Carrera L, Van Cauwenbergh N, Gebremedhin ET, Piton G, Tacnet J-M, Altamirano MA, et al. Designing Natural Assurance Schemes with Integrated Decision Support and Adaptive Planning. In: López-Gunn E, van der Keur P, Van Cauwenbergh N, Le Coent P, Giordano R, editors. Green. Water Risks Nat. Assur. Schemes, Cham: Springer International Publishing; 2023, p. 113–33. https://doi.org/10.1007/978-3-031-25308-9_7.
[111] Dartée KWJ, Biffin T, Peña K. The Opportunities and Challenges for Urban NBS: Lessons from Implementing the Urban Waterbuffer in Rotterdam. In: López-Gunn E, van der Keur P, Van Cauwenbergh N, Le Coent P, Giordano R, editors. Green. Water Risks Nat. Assur. Schemes, Cham: Springer International Publishing; 2023, p. 325–45. https://doi.org/10.1007/978-3-031-25308-9_16.
[112] Abhijith KV, Kumar P, Gallagher J, McNabola A, Baldauf R, Pilla F, et al. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review. Atmos Environ 2017;162:71–86. https://doi.org/10.1016/j.atmosenv.2017.05.014.
[113] Guo Z, Zhang Z, Wu X, Wang J, Zhang P, Ma D, et al. Building shading affects the ecosystem service of urban green spaces: Carbon capture in street canyons. Ecol Model 2020;431:109178. https://doi.org/10.1016/j.ecolmodel.2020.109178.
[114] Buccolieri R, Gromke C, Di Sabatino S, Ruck B. Aerodynamic effects of trees on pollutant concentration in street canyons. Sci Total Environ 2009;407:5247–56. https://doi.org/10.1016/j.scitotenv.2009.06.016.

[115] Rötzer T, Rahman MA, Moser-Reischl A, Pauleit S, Pretzsch H. Process based simulation of tree growth and ecosystem services of urban trees under present and future climate conditions. Sci Total Environ 2019;676:651–64. https://doi.org/10.1016/j.scitotenv.2019.04.235.
[116] Weissert LF, Salmond JA, Schwendenmann L. Photosynthetic CO2 uptake and carbon sequestration potential of deciduous and evergreen tree species in an urban environment. Urban Ecosyst 2017;20:663–74. https://doi.org/10.1007/s11252-016-0627-0.
[117] Harrison PA, Berry PM, Simpson G, Haslett JR, Blicharska M, Bucur M, et al. Linkages between biodiversity attributes and ecosystem services: A systematic review. Ecosyst Serv 2014;9:191–203. https://doi.org/10.1016/j.ecoser.2014.05.006.
[118] Kabisch N, Frantzeskaki N, Pauleit S, Naumann S, Davis M, Artmann M, et al. Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecol Soc 2016;21.
[119] Colléony A, Shwartz A. Beyond Assuming Co-Benefits in Nature-Based Solutions: A Human-Centered Approach to Optimize Social and Ecological Outcomes for Advancing Sustainable Urban Planning. Sustainability 2019;11:4924. https://doi.org/10.3390/su11184924.
[120] Bockarjova M, Botzen WJW. Review of economic valuation of nature based solutions in urban areas. Utrecht: Utrecht University; 2017.
[121] Champ PA, Boyle KJ, Brown TC, editors. A Primer on Nonmarket Valuation. vol. 3. Dordrecht: Springer Netherlands; 2003. https://doi.org/10.1007/978-94-007-0826-6.