Ecological Indicators 183 (2026) 114627

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Nature-based solutions and urban biodiversity conservation in the Global South☆

Ravi Jambhekar [a,1], Ryan Satish [a], Swarnika Sharma [a], Gayatri Bakhale [a], Priya Ranganathan [a,b], Dilip G.T. Naidu [a], Kadambari Deshpande [a], Jagdish Krishnaswamy [a,*,1]

[a] *School of Environment and Sustainability, Indian Institute for Human Settlements (IIHS), No. 197/36, 2nd Main Road, Sadashivanagar, Bengaluru 560 080, Karnataka, India*

[b] *Ashoka Trust for Research in Ecology and the Environment (ATREE), Royal Enclave, Sriramapura, Jakkur Post, Bangalore 560 064, Karnataka, India*

ARTICLE INFO

Keywords:
urban ecosystems
urban sustainability
urban conservation planning
urban biodiversity refugia

ABSTRACT

Urban areas face significant environmental challenges, requiring integrated solutions. As urbanization increasingly impacts biodiversity, cities must contribute to its conservation as per global goals. Nature-based Solutions (NbS) are widely adopted to tackle urban challenges. However, evidence for their success in urban biodiversity conservation remains weak. Although NbS are defined by using native biodiversity for net ecosystem services benefits, many NbS projects feature exotic and invasive species. We conducted a systematic literature review and qualitative synthesis, following PRISMA guidelines, on 67 studies published in English (2013-2023) from the Global South to assess urban NbS biodiversity outcomes across 83 unique cities. Only 55 studies evaluated biodiversity outcomes, with just 43% identifying specific flora or fauna. The NbS types included blue-green infrastructure, urban green spaces, urban forests (each 22%), and green roofs (18%). Our analysis revealed a critical methodological inadequacy: measuring biodiversity co-benefits with pre- and post-implementation data or evidence was rare. Crucially, not one study included necessary baseline assessments to effectively measure biodiversity gains. Furthermore, native biodiversity, mentioned as a co-benefit, was often poorly described. Through our systematic literature review, we found 27 studies mentioning use or presence native species and 16 studies mentioning exotic species in the NbS implemented. We found that including an ecologist in the author teams positively influenced the reporting of specific species ($p<0.05$). In the absence of robust data, our ability to integrate NbS into global conservation goals is weakened. Our synthesis highlights key gaps, best-practices and recommendations to strengthen native biodiversity considerations in NbS in the global south.

1. Introduction

Urban spaces are increasingly subject to intense environmental hazards that undermine the synergies among economic growth, social inclusivity, and sustainable development goals (SDGs) that are essential for the concept of ‘sustainable cities’ (Sachs et al., 2019).

Climate change and urbanisation are emerging as two major drivers of biodiversity and ecosystem changes and demand urgent attention (IPBES et al., 2019). One approach to link urban development and ecological processes is to recognise Nature-based Solutions (NbS) for their potential to address both the biodiversity crisis and human well-being (Kabisch et al., 2022). NbS uses the positives of ecological mechanisms and ecosystem functions to solve urban problems. Today, NbS are a major part of the discourse and practice across the globe (Martín et al., 2020). They are now widely cited in the two major science-policy platforms, the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). (Pörtner et al., 2021; Seddon et al., 2020; Seddon et al., 2021). The widely adopted definition of NbS as established by IUCN Resolution 069 (World Conservation Congress, 2016) is, “actions to protect, sustainably manage, and restore natural or modified ecosystems that address social challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits.” According to the United Nations, NbS are defined

☆ This article is part of a Special issue entitled: ‘NbS for Holistic Management’ published in Ecological Indicators.

* Corresponding author.
E-mail address: jagdish.krishnaswamy@iihs.ac.in (J. Krishnaswamy).

[1] These authors made equal contributions.

https://doi.org/10.1016/j.ecolind.2026.114627
Received 30 May 2025; Received in revised form 9 January 2026; Accepted 10 January 2026
Available online 19 January 2026

as "actions aimed at protecting, conserving, restoring, and sustainably managing natural or modified terrestrial, freshwater, coastal, and marine ecosystems, which address social, economic, and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services, resilience, and biodiversity benefits" (United Nations Environment Assembly, 2022). While both the IUCN (2020, 2025) and UN (2022) definitions of NbS emphasize ecosystem protection, management, and restoration to address societal challenges, they differ in scope and emphasis. The IUCN provides a concise, conservation-focused framing centered on human well-being and biodiversity, whereas the UN definition broadens this to include terrestrial, freshwater, coastal, and marine ecosystems, explicitly linking NbS to social, economic, and environmental challenges, as well as ecosystem services and resilience. The IUCN and UN definitions thus suggest that the main purpose of NbS is to solve challenges related to development and human well-being, while also providing tangible and measurable co-benefits to biodiversity. Ideally, such biodiversity co-benefits should include restoration and maintenance of native species and ecosystem functions (Ahmad and Hassan, 2025). For instance, a constructed wetland with native species serves better as an NbS than one with exotics in the context of cleaning the water and providing balanced support for local aquatic ecosystems (Shahid et al., 2020).

Furthermore, there is a section of NbS known as Ecosystem-based Adaptations or EBA, that focuses mainly on climate change challenges (Coll et al., 2009) and is a preferred term in some contexts (Brink et al., 2016), such as when countries are trying to assess the role of ecosystems in climate change adaptation and to increase ecosystems' resilience towards climatic shocks. EBAs include interventions such as creating green and blue infrastructure that help reduce heat stress from climate change by providing shade to citizens and latent cooling through transpiration and evaporation (Wijeratne et al., 2025).

When NbS and EbA are studied by scholars from the Global North, a large number of them focus on the potential of urban areas to contribute significantly to global conservation targets (e.g., Brink et al., 2016; Kowarik, 2023; Qian et al., 2023; Li et al., 2025). However, in the Global South, there hasn't been a systematic evaluation of the biodiversity benefits of different types of NbS (terrestrial and aquatic, combined with grey infrastructure or the built environment), even though urbanization and land-use change are major drivers of biodiversity loss there. In the Global South, many NbS have multiple-use areas serving several stakeholders and hence can be used in combination with or as part of other types of interventions (Cohen-Shacham et al., 2016). This lack of systematic evaluation in the Global South is often linked to limitations in institutional capacity, funding, and long-term monitoring, alongside competing development priorities. Moreover, NbS in these regions are frequently designed for multiple uses—such as water provision, flood control, and livelihoods—which can dilute the focus on biodiversity outcomes compared to the more research-intensive approaches prevalent in the Global North (Bonelli et al., 2025). Some existing interventions in the Global South which may qualify as NbS are not described in the literature and in addition a smaller pool of trained ecologists in some countries have focused on non-urban ecosystems (Barbarwar et al., 2023; Wolff et al., 2023). Moreover, despite high relevance, a perceived lack of NbS adoption in the tropical regions of Global South compared to temperate regions of Global North could be due to multiple factors, including use of different phrases, terminologies, or lexicons depending on different region and contexts such as green infrastructure, natural resource management, landscape-based solutions, ecosystem-based adaptation, social technology, etc (Abera et al., 2025). Higher research focus on temperate ecosystems also mirrors the varying level of existing policies and pledges across regions (Chausson et al., 2020). In terms of natural climate solutions (NCS), tropical regions have received more focus as they hold higher potential (61%) and the highest gross carbon fluxes compared with temperate and boreal latitudes (Griscom et al., 2020). Major drivers behind the different levels of implementation of NCS across tropical and temperate regions include engagement of indigenous peoples and local communities, performance-based finance, and technical assistance (Schulte et al., 2022). Also, biodiversity outcomes through NbS are of two kinds: (1) green spaces that provide refugia to flora and fauna (promoting SDG 15: Life on Land) which especially includes native biodiversity (Nicholls and Altieri, 2013), and (2), as components of the NbS mechanism, like wetland plants that absorb nutrients in bioswales or constructed wetlands, helping in wastewater treatment (Fazlolahi and Eslamian, 2014).

Despite widening dimensions in approaches to responding to an ongoing global biodiversity crisis, traditionally there has been a reticence towards inclusion of biodiversity in urban ecosystems. Much of the discourse and concerns have largely been restricted to biodiversity conservation in the rural, semi-wild, and wild areas. Given the fast-growing nature of urbanisation and urban spaces, especially in the Global South, concerns about the role of urban areas in impacting, conserving, and restoring native biodiversity are gaining traction (Simkin et al., 2022). This is particularly relevant in the context of the '30X30 global target' of setting aside 30% of inland waters, terrestrial ecosystems, and marine/coastal areas for conservation by 2030 (Sengupta et al., 2024; Srivathsa et al., 2023). It is clear that with urbanization becoming a global driver of land-use and land-cover change and with a large percentage of people in the global south expected to be living in urbanizing spaces in the coming decades, biodiversity conservation has to take centre stage in urban spaces as well. NbS can help address the biodiversity challenge in urban spaces. As an example, a case study from Brazil showcased the use of NbS to increase native fauna through the "Green my Favela" project (Ronchi and Arcidiacono, 2018) or the use of native flora to increase native and migratory fauna, as found in the review articles from other parts of the world (Shah Mohammad et al., 2022). Moreover, many green interventions and green spaces are often perceived as NbS without any proper understanding or evidence of their actual contribution to native biodiversity or how the ecological mechanisms and functions based on native species helped solve the problem. Studies from Global North indicate that while cities are explicitly contributing to biodiversity through quantitative, project-based targets, these efforts primarily focus on ecosystem-level goals, such as habitat integrity and connectivity. NbS projects do not address specific species or genetic diversity, and adding this dimension to existing projects will be essential in the future (Xie and Bulkeley, 2020).

The evidence on the contribution of NbS to native biodiversity in terms of specific flora and fauna and maintenance of viable habitats for overall tropical biodiversity in the Global South, needs to be measured and assessed. In the absence of information and data, our ability to improve and extend NbS as part of regional, national, and global biodiversity conservation goals and to enable urban NbS to become a refugia for biodiversity will be weakened, and hence, clear links between NbS and conservation goals need to be urgently established (Key et al., 2022; van Rees et al., 2023).

In this study, we systematically assess the biodiversity dimensions of NbS that encompass one or more components of terrestrial, aquatic, and built environments across the Global South in the urban context using published studies. Despite the growing recognition of NbS as multifunctional tools for addressing urban challenges, there remains limited clarity on how biodiversity outcomes are conceptualized, measured, and reported across diverse urban contexts in the Global South - this study seeks to address that gap. For example, many NbS projects focus on immediate services (e.g., stormwater management, temperature reduction) but whether these implemented NbS help in biodiversity increase is unclear.

With the gaps highlighted above our objectives were:

1. To assess published studies conducted in the Global South urban spaces, of diverse projects across sites, that qualify as NbS in terms of their design and stated objectives.

2. To gather evidence on the specific biodiversity dimensions of these NbS interventions.
3. To identify gaps in data, knowledge, reporting and design that hinder the effectiveness and adoption of NbS as a strategy for urban biodiversity conservation.

2. Methods

2.1. Literature review

The search for literature was based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021). Search terms were across Scopus and PubMed databases, and the search was geographically restricted to the countries in the Global South. We considered papers from the past ten years, that is, published between 2013 and 2023 and written in English. The term "nature-based solutions" was first coined in 2008, and only after that did the field start developing. The data is very sparse in the initial few years, and hence we decided to review the literature for the past ten years. We considered papers in the English language, as translating papers from other languages was not possible, and that could lead to misinterpretation and loss of valuable information in the translation process. The search was carried out in 2023. Our purpose for this review was to ensure that studies capture the role of NbS on urban biodiversity along with other climatic and societal impacts with countries in the Global South.

A CSV file with the metadata was obtained from Scopus and Pubmed. The first 10,000 titles from each database were screened, and any repeats across the two databases were removed. The screening process involved a careful consideration of the inclusion and exclusion criteria (as mentioned in Box 1). Further screening was done based on “Title”, “Abstract” and “Full text” in the following manner: The first shortlist of relevant papers was created based on the titles of the papers. Next, the abstracts of these were read to determine whether the papers discussed NbS and their relationship with biodiversity in the context of the Global South. Any studies that did not fulfil these criteria were removed from the search; the number of papers removed at each step is mentioned in (Figure 1). The studies were included with a focus on topics related to NbS, urban biodiversity, and ecosystem services, withing Global South. Moreover, the inclusion criteria incorporated a broad range of keywords including ecological restoration, blue-green infrastructure, urban greening, and associated aspects such as flora, fauna, soil, water, pollution, and urban heat islands, etc. In the round of screening literature our search words produced papers from several topics, some of which were not related to biodiversity conservation. These were further filtered out by adding the NOT category in the search string, which helped exclude topics such as “public health”, “human health”, “meta-analysis”, “child health”, “disease”, or “health care” and studies focused on the Global North that were not relevant to our study (refer Box 1).

We are aware that our strategy for literature search may have caused us to miss certain studies that are, in fact, very closely related to NbS applications. These probably did not appear in our literature search, as they did not use the words ‘Nature-based Solution’ in their title or keywords, or the focus of their study was not directly related to biodiversity conservation, but they may be very valuable in their findings. However, including them in this review was beyond our scope, given our methodological constraints. The loss of information may influence the results, particularly for NbSs with limited representation in the literature. In contrast, the interpretation and biodiversity outcomes of widely documented NbSs are unlikely to be substantially affected. Finally, out of the 67 shortlisted papers, 55 papers were finalised for the systematic literature review. Out of the 67 shortlisted papers, 21 were review articles and 46 were primary articles (Figure 1). We did not include reports and grey literature for our study. After careful reading we finally excluded additional 12 articles ending up with 55 articles. The exclusion criteria for the papers were – (1) papers that did not have information and data on specific study sites or biodiversity, and (2) articles that were modelling based or the ones that focused only on environmental variables.

31 primary research articles were used for the synthesis section, as we used these primary papers to extract data (Appendix Table 1). Review articles were not used for synthesis, as many of the articles did not mention the exact locations, species identity, or co-benefits to biodiversity in detail.

2.2. Data collection for literature synthesis

For synthesis, we shortlisted a total of 31 research articles on NbS and urban biodiversity (Figure 1; Appendix Table 2), which included 29 studies that focused on primary research and two review articles with primary data on NbS. We adopted qualitative synthesis also called meta-synthesis (Timulak, 2014) to synthesize key insights and outcomes from the literature assessed. Qualitative syntheses have an interpretive and pattern recognition ability rather than aggregation (Walsh and Downe, 2005). The meta-analyses / synthesis is an important technique for studies with qualitative outputs and can deepen understanding of the contextual dimensions of NbS in the Urban across the Global South. Each of these studies was from the Global South, and we carried out analysis to understand their distribution across the region and their co-benefits related to climate, social, and biodiversity dimensions. For each study, we obtained information about the following NbS categories—green roofs, urban forests, blue-green infrastructure, urban green spaces, floating wetlands, and phytoremediation. We also considered the year of publication and the year in which the NbS was initiated and collected the relevant metadata. In case a study had multiple NbS types—for example, Wolff et al. (2023) evaluated three NbS types across multiple categories and across eight countries in Southeast Asia and Pacific Islands—we collected the geographical locations of each site and its metadata. If the exact location of sites from the shortlisted studies was not mentioned, the geolocation of the country's capital city was considered in lieu of the precise study site(s).

We obtained spatial information on continents using shapefiles from Natural Earth - Land (https://www.naturalearthdata.com/downloads/10m-physical-vectors/10m-land/), and the income status (low income, lower middle income, upper middle income, high income) of each country from The World Bank database using data from 2023 (https://data.worldbank.org/). We noted whether the research papers included information on native, exotic, or invasive species; this information on species identity was restricted to the family level. Finally, we also determined whether the paper was relevant to sustainable development goals. From our review, we found that the studies largely focused only on the following five SDGs: (1) SDG 1: No poverty, (2) SDG 2: Zero Hunger, (3) SDG 3: Good Health and Well-Being, (4) SDG 11: Sustainable Cities and Communities, and (5) SDG 13: Climate Action.

To evaluate the co-benefits of NbS on urban biodiversity, we focused on three outcomes of NbS—climate, biodiversity, and societal services (Figure 2). We focused on climate adaptation, climate mitigation, and the urban heat island effect as part of climate services. For biodiversity benefits, we evaluated outcomes in terms of vegetation, species diversity, providing habitat, ecosystem restoration, and ecosystem management. Finally, for societal benefits, we explored various services ranging from water quality and retention, thermal comfort, soil health, socio-cultural impact, reduction in pollution load, ornamental or medicinal use, effect on human wellbeing and health, food provision, flood mitigation, economic development, awareness generation on biodiversity and the NbS, and air quality.

Under each service, we categorised whether the NbS implemented had a demonstrated positive impact (i.e., the effect increased or was supported by the NbS), negative (a decline in the outcome/service due to NbS implementation), or the impact was unclear (e.g., effect of NbS varied spatially or temporally). Such detailed metadata extraction provided structure for analysing the role and effectiveness of NbS across various social and environmental contexts. Finally, all the results were

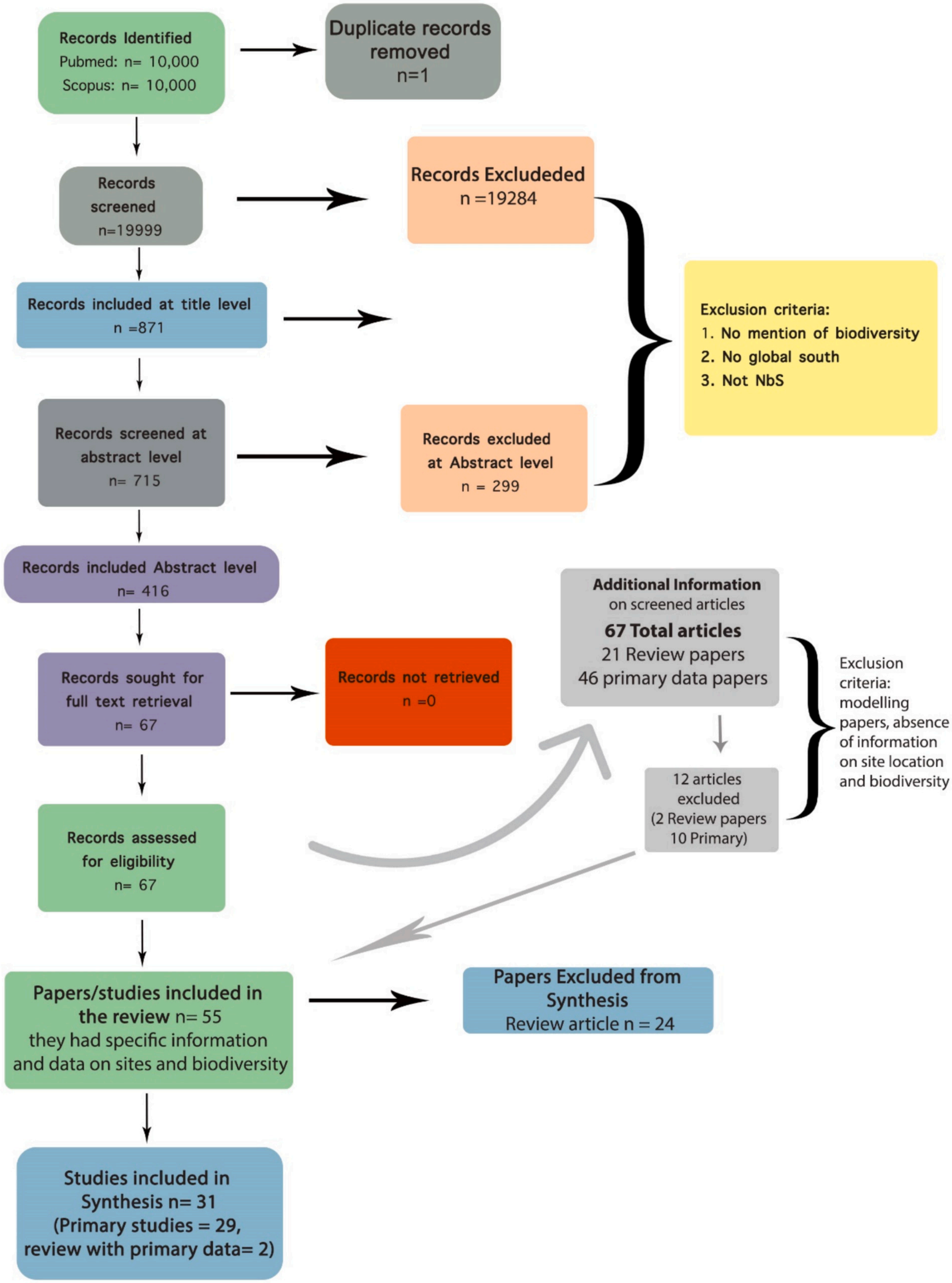

Fig. 1. Stepwise flowchart for identifying and shortlisting literature on urban biodiversity conservation through NbS interventions in the Global South (based on PRISMA guidelines). Figure adapted from Page et al., 2021.

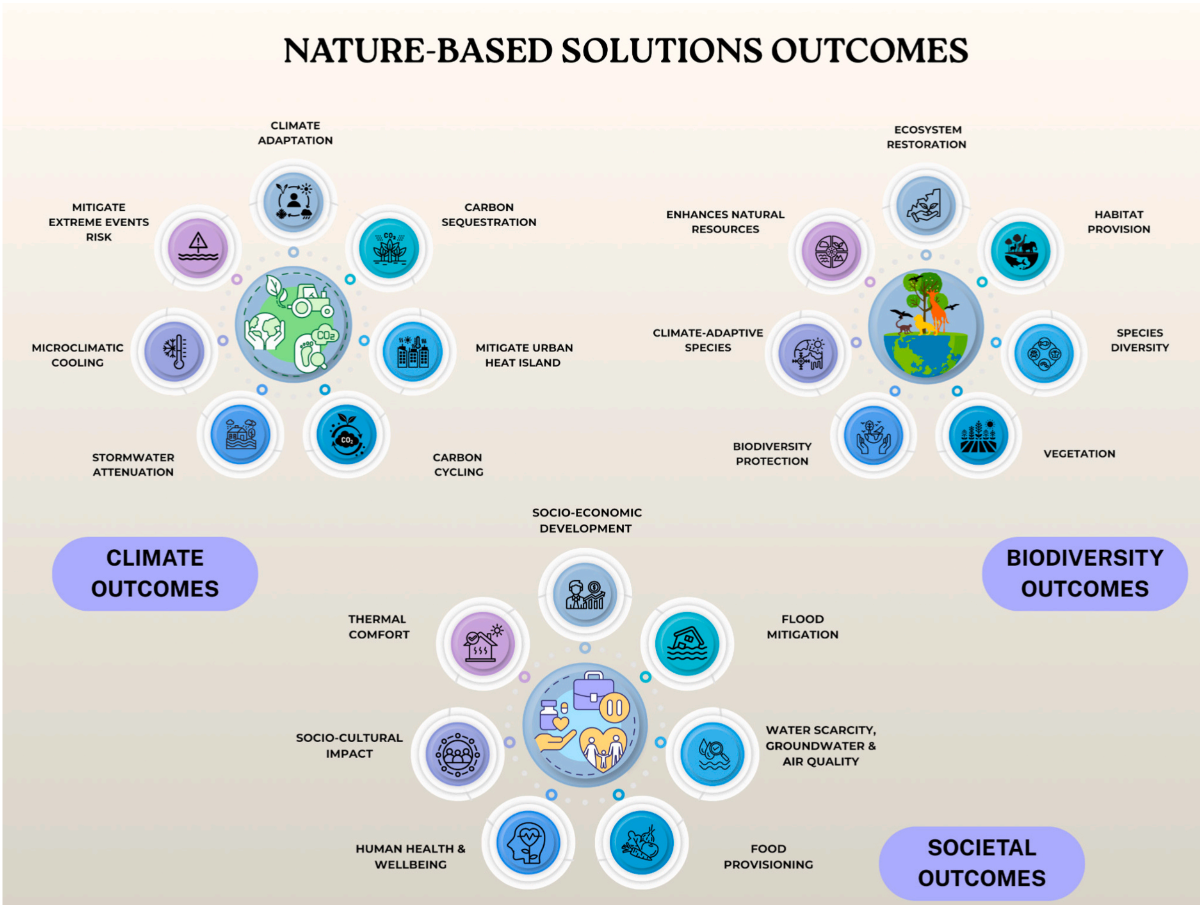

Fig. 2. Based on the assessed literature, the figure maps the co-benefits of NbS outcomes with their indicators. The outcomes are bucketed under three major categories: climate, biodiversity, and societal, along with their respective indicators.

collated and summarised using open-source statistical software R (version 4.32) using the “terra” and “ggplot2” packages.

Using the data extracted for NbS benefits we did additional analysis to see if there is effect of spatial heterogeneity on NbS effectiveness and if having authors from life science background in the study added to reporting of biodiversity. We describe the details of this analysis below. Many papers that describe NbS sometimes have multi-disciplinary teams and may not always have an ecologist or a biologist as an author. We investigated how the description and analyses of NbS in terms of native biodiversity was positively influenced by the presence of an ecologist or biologist in the author team. The response variable was whether the paper reported specific species of biodiversity or not (1 or 0) and the covariate was presence or absence of an ecologist or biologist amongst the authors in the 55 studies we assessed. We tested the hypothesis by fitting a logistic regression model in the statistical package R.

We evaluated the background characteristics of the cities where NbS were implemented to understand whether the form of the city was related to NbS. For this, we use four variables – urban area (in km^2), total built-up volume (in m^3), biogeographic zone (Koppen Climate classification) and the green cover (measured as the share of green area in built-up area as %). The data for these variables was obtained from the Global Human Settlement Layer (Pesaresi et al., 2024). The city names for each of the primary articles were matched with the settlement layer name from the Global Human Settlement Layer database, and the data for the above four variables were extracted for each data point (study location). The data for urban area, built-up volume, Koppen classification and green cover was for 2025, 2020, 2025, and 2025 respectively.

Each NbS study in a specific city received a score of 0 or 1 on three effectiveness indicators on benefits: biodiversity, climate and socio-economic. These were added to give a range of 0-3, and we assessed distribution of these combined scores using a histogram. We tested regression of these combined scores against city size, percentage of green spaces with respect to build area and land use intensity.

3. Results and discussion

Implementation and studies on NbS in the Global South were comparatively fewer than in the Global North (McPhearson et al., 2025). Most of the studies were from Africa, with a glaring lack of studies from Southeast Asia, India, and other Latin American countries (Figure 4, Appendix Figure S1, Figure S3). However, in the past 10 years, a significant increase in the number of NbS implementations has been reported in South Africa and Asia (Appendix Figures S1, S3). We also found that certain NbS are more readily applied and more widely used or reported than others. For example, the most implemented NbS in the Global South were green roofs, urban forests, and urban green spaces (Appendix Table S1, Figure 3, Figure S4). Drier biomes (Arid, deserts and steppes) in general show lower NbS implementation and lower outcome (biodiversity, climate, socioeconomic) in comparison to tropical Savannahs, tropical monsoon and tropical forest regions (Figure 4). Although some studies showed that NbS resulted in an increase in biodiversity ranging from conservation of specific taxa to conservation of multiple species and habitats, our analyses revealed that the practice of measuring biodiversity co-benefits from before as well as after NbS projects is an exception rather than the norm. Only 15 out of 55 studies report diversity indices, we have collated this information in Appendix Table S2. Additionally, relatively fewer studies focus on the biodiversity component, i.e., whether the species are native, and other co-benefits

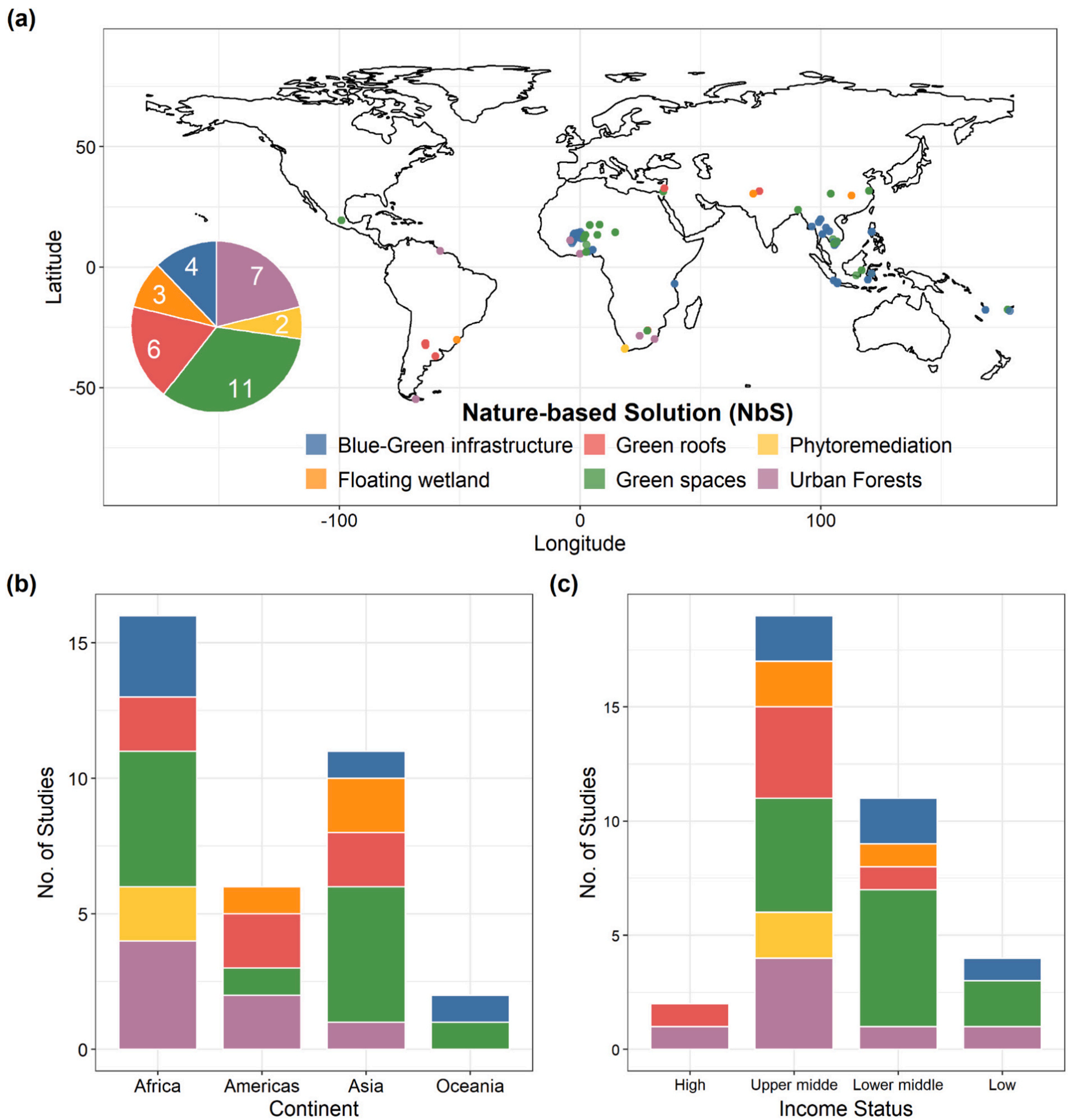

Fig. 3. The distribution of NbS interventions from the 29 primary articles and two review articles with primary data in the Global South. The geographical locations of the NbS interventions as a map in (a); across different continents in (b); and the distribution of NbS studies by income status obtained from The World Bank (c). The colors represent the NbS type studied in the corresponding locations. The pie chart in (a) represents the number of studies in each category.

such as solutions towards SDGs (Figure 5). Most research on NbS in the Global South focused on human-centric ecosystem services such as rainwater harvesting and improved water management, energy efficiency, pollution and greenhouse gas emission reduction, and reduction of the heat island effect in growing cities (Ahmad and Hassan, 2025) (Figure 6). In Shenyang City, urban blue-green landscapes have contributed to the mitigation of urban heat island by constructing cooling corridors based on actual cooling demand, and the cooling energy can be diverted from suburban to urban areas via flow corridors (Guan et al., 2025) . Furthermore, many projects designated as 'NbS' in the literature may not qualify as NbS as per the IUCN criteria, and contrarily many projects that are actually NbS may not be described as such (IUCN 2020).

In the following sections we summarise the research findings, merits, drawbacks, and solutions, for important NbS categories in the Global South. Where there were limited studies, but the NbS type was novel (for example, green belts and sustainable drainage systems), we have pooled the findings for the ease of reporting. Finally, we suggest important guidelines and checklists for donors, practitioners, and project reviewers to ensure that a project qualifies as an NbS both in letter and spirit with a focus on biodiversity conservation in the Global South.

3.1. *Summary of findings of NbS types*

3.1.1. *Blue-green infrastructure*

Blue-green infrastructure (BGI) is defined as a network of natural infrastructures that includes blue (aquatic) and green (terrestrial) spaces embedded in grey (built) infrastructure. We find that BGI was one of the most common NbS (n = 12, including 8 reviews and 4 primary) in the Global South. Most studies generally reported that BGI supports urban

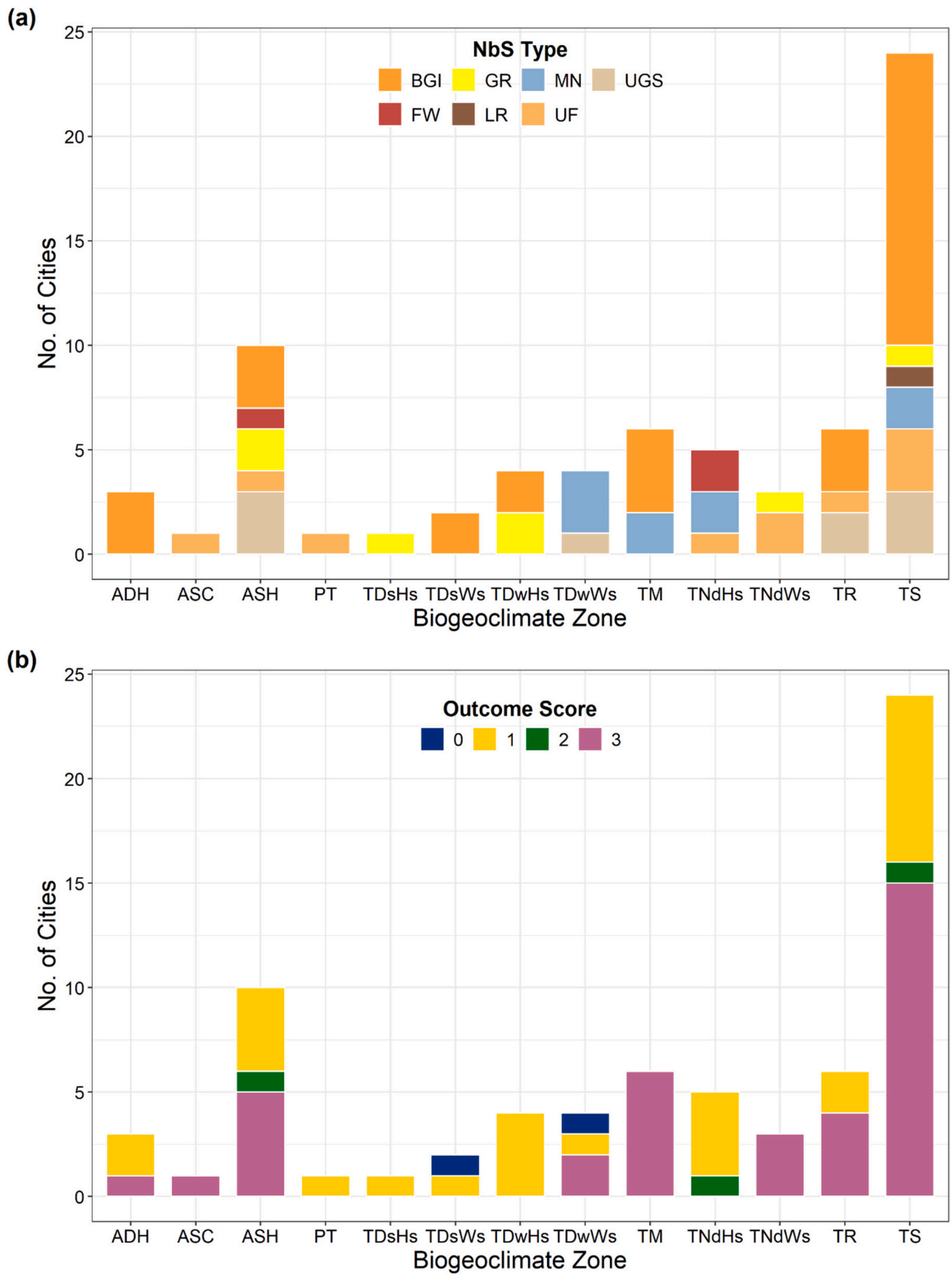

Fig. 4. (a) Distribution of number of cities implementing different types of Nature-based Solutions (NbS) across various biogeoclimate zones.
[The stacked bars represent Nature-based Solutions (NbS) types (BGI = Blue-Green Infrastructure; GR = Green Roofs; MN = Multiple NbS; UGS = Urban Green Spaces; FW = Floating Wetland; LR = Landscape Restoration; UF = Urban Forests)]
(b) Scoring of NbS effectiveness indicators across biogeographic and climatic zones.
Footnote: The scoring was done as 0 or 1 given to each NbS type on three effectiveness indicators on the NbS outcomes: biodiversity, climate and socio-economic. Further, the assessment was done by adding these scores to give a range of 0-3.
[Biogeoclimate Zones (ADH = Arid, Desert, Hot; ASC = Arid, Steppe, Cold; ASH = Arid, Steppe, Hot; PT = Polar, Tundra; TDsHs = Temperate, Dry summer, Hot summer; TDsWs = Temperate, Dry summer, Warm summer; TDwHs = Temperate, Dry winter, Hot summer; TDwWs = Temperate, Dry winter, Warm summer; TM = Tropical, Monsoon; TNdWs = Temperate, No dry season, Warm summer; TR = Tropical, Rainforest; TS = Tropical, Savannah)]

biodiversity and can restore ecosystems and increase species richness and diversity, thus conserving native species (Amado et al., 2020; Nyamekye et al., 2021; Pauleit et al., 2021; Wolff et al., 2023), promoting SDG 15: Life on Land. Cities with open green spaces, institutional compounds, and public parks host more biodiversity than the greenery on roadsides or farmlands (Jambhekar et al., 2025; Nassary et al., 2022). Integrating BGI into stable urban land-use areas like campuses can contribute to biodiversity conservation as evidence suggests a large

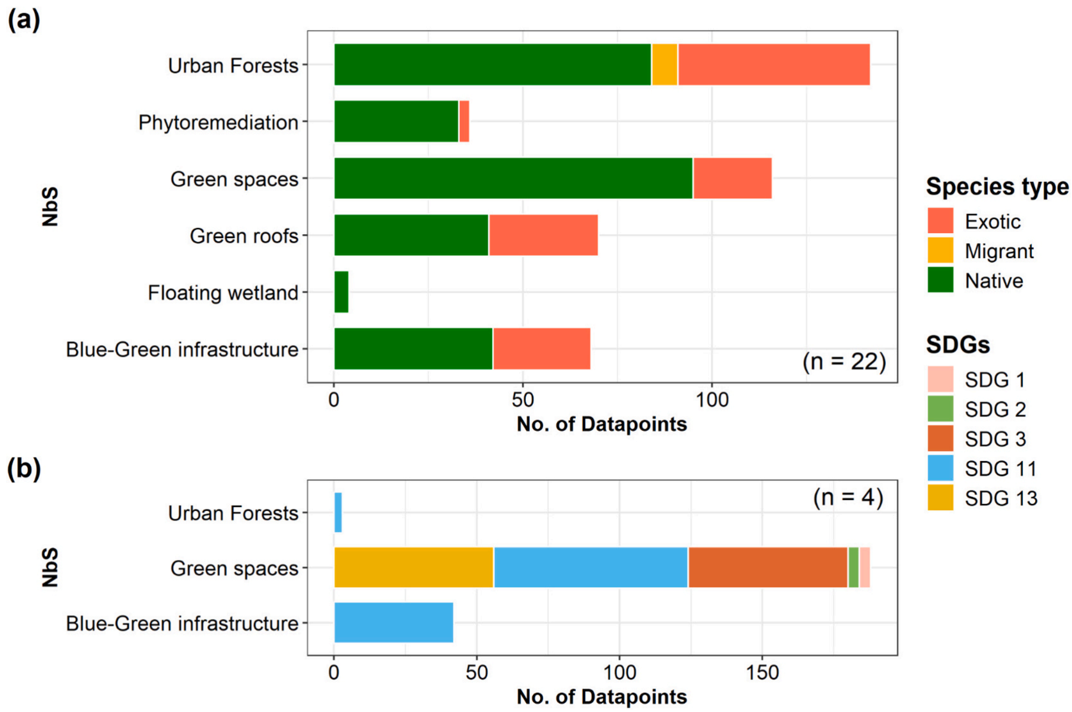

Fig. 5. Distribution of data from NbS interventions on biodiversity conservation and co-benefits to Sustainable Development Goals (SDGs). Studies that mentioned biodiversity information on native, exotic, and migrant species across different NbS types (a). Co-benefits of NbS types on other SDGs (b). The colors represent the species type in (a) and specific goals in (b). The total number of studies that have evaluated species type and SDGs are shown in the insets of (a) and (b), respectively. See methods for the details on the names of each SDG.

proportion of India's birds, bats and butterflies can be found in educational campuses (Dhyani and Krishnaswamy, 2025). This data clearly indicates the importance of BGI as a stepping stone to conserving biodiversity in cities and also as corridors for wildlife movement (Amado et al., 2020; Wolff et al., 2023). Recently, BGI has also been used for stormwater and flood mitigation, biodiversity conservation, improved air quality, and heat island effect mitigation (Ghofrani et al., 2017). Effective implementation of BGI using native species can promote ecosystem multifunctionality, thereby enhancing the ecological resilience of rapidly expanding urban areas (Amado et al., 2020; Gharbi et al., 2023). However, their impact and effectiveness may vary depending on the location and types of management measures used. For instance, the use of some exotic and especially invasive species as plant choices for BGI often leads to ecosystem disservices. A native weed from Australia, *Paspalum dilatatum,* which has become a naturalised exotic species in Egypt, is grown in urban gardens. Hassan and Mohamed (2020) found that it exhibited more allelopathic compounds, resulting in the decline of native species diversity and coverage in urban gardens. Furthermore, a study found that a well-maintained blue infrastructure leads to better appreciation of ecosystem services by the local residents, whereas neglected systems imply trade-offs with limited emphasis on ecosystem services (Chowdhury et al., 2025). Ineffective implementation of BGI practices may pose a risk to human health and ecosystem services. For instance, the introduction of alien tree species as NbS has impacted the local ecosystems in South Africa, as they often outcompete indigenous species (Gharbi et al., 2023), and a case of a vertical greening system that attracted urban pests in Sub-Saharan Africa threatening public health and food is also reported (Adegun et al., 2022). Overall, the positive implications of BGI for biodiversity are evident, as it has been evident that BGI increases species richness and diversity (Perrelet et al., 2024) but detailed species level and population level studies are lacking from the Global South.

One major drawback for the implementation of BGIs in urban areas is scalability (Wolff et al., 2023). Since space is a real constraint in cities, expansion of BGIs beyond a certain point is not feasible. Additionally, when cities expand, these green and blue spaces are often lost, being replaced with built infrastructure (Hwang et al., 2020), thereby making these interventions unsustainable. Another important aspect in the implementation of BGIs in urban areas is the involvement of local communities, who often design solutions based on their needs and also help in its maintenance (Wolff et al., 2023). Local communities can be incentivised to promote BGI by planting fruiting trees or herbal gardens, which provide them with co-benefits as they can harvest fruits or medicinal herbs for consumption or for sale to generate extra revenue, and at the same time, these plants attract birds, small mammals, and insects and also provide food resources to the fauna. Socio-cultural differences influence perceptions of blue infrastructure with long-term residents prioritising certain ecosystem services more than short-term residents. Involving residents in resource management can integrate local urban knowledge into decision-making and foster sustainable, resilient, and inclusive urban environments (Chowdhury et al., 2025).

Even though there has been an increase in studies implementing BGI in recent years (Appendix Figure S2, Figure S3), there is scope for a lot more studies to be done in the Global South. Barriers and challenges such as fragmented governance structures, lack of reliable data, social inequality, absence of proper guidelines and expertise, a lack of shortage of funding mechanisms, the non-involvement of all stakeholders, and lack of land availability often hinder the effective implementation of BGI in the Global South (Cobbinah et al., 2022; Nassary et al., 2022; Pauleit et al., 2021; Wolff et al., 2023). In order to overcome some of these barriers and help with smooth implementation and functioning of BGI in urban areas of the Global South, there is a need to identify enablers and opportunities in terms of socio-cultural values, inclusive participation from stakeholders, research and innovation, strong financial support, political will with effective policies and regulations, and institutional structures (Caetano et al., 2021; Gharbi et al., 2023; Nassary et al., 2022; Nyamekye et al., 2021; Pauleit et al., 2021).

3.1.2. *Urban green spaces*

Urban green spaces consist of parks, campuses, residential greenery,

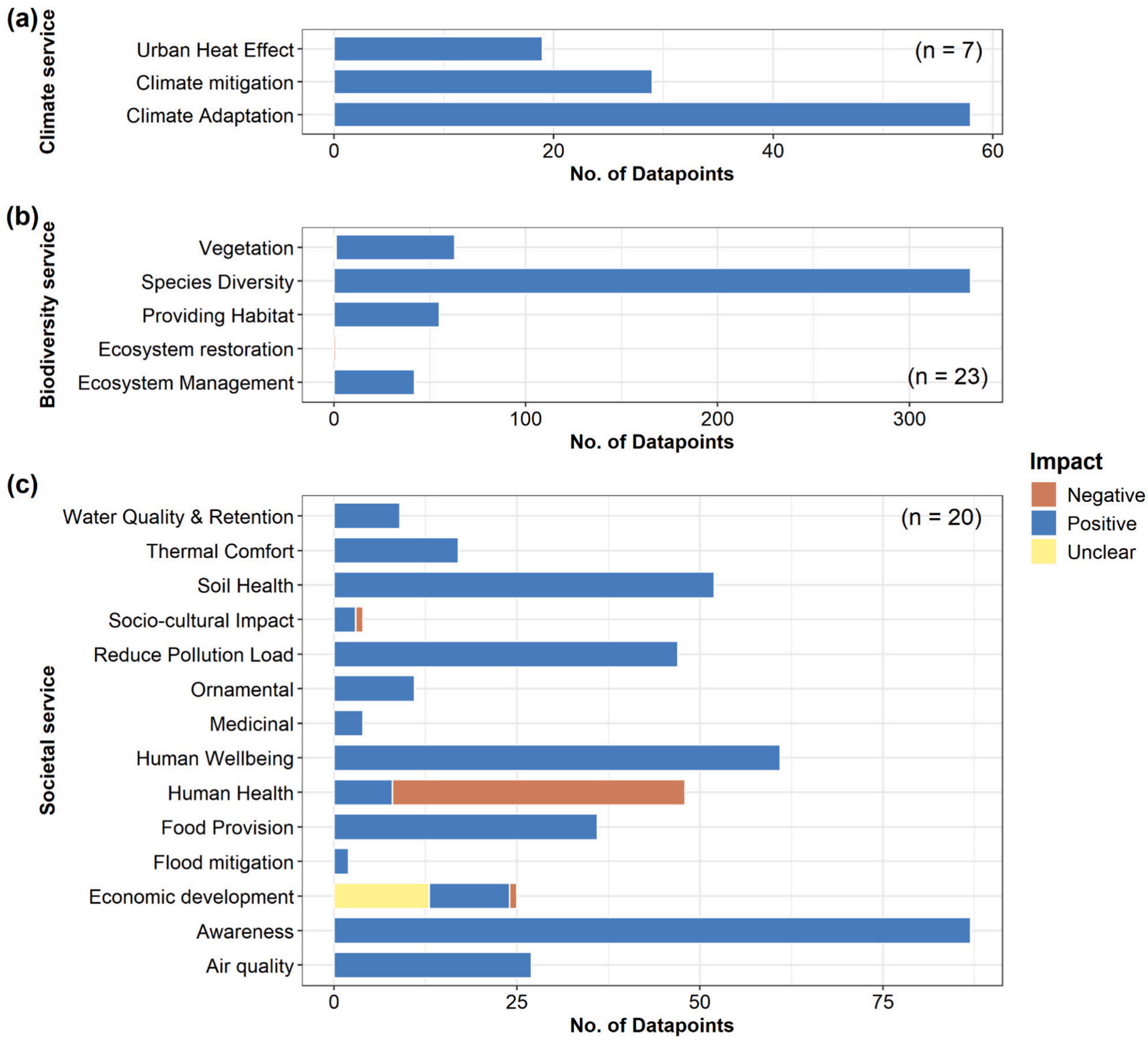

Fig. 6. Co-benefits of NbS types across biodiversity, climate, and societal outcomes. The benefits were classified based on multiple services under Climate (a), Biodiversity (b), and Society (c). The total number of studies under each co-benefit category is shown in the inset in brackets. The colors represent whether the impact of NbS on that particular service was positive (blue), negative (red), or unclear (yellow). See methods for details on the classification of impacts.

and nature preserves (World Health Organization, 2016). Urban green spaces can be any green space and do not include blue spaces. A total of 12 research papers (8 primary and 4 review articles) discussed urban green spaces as a type of NbS in cities of the Global South. These studies reported that urban green spaces improved soil carbon, soil microflora, and other biodiversity aspects in terms of species richness and abundance (Bayala et al., 2020; Chowdhury et al., 2021; Li et al., 2023). Green spaces in cities mitigated urban heat by lowering the temperatures by providing shade and cooling, thereby contributing to biodiversity conservation (Ballinas and Barradas, 2015). A recent study has demonstrated that heat islands in the city have negative effects on birds in the global south (Jambhekar et al., 2025). This could potentially lead to biodiversity loss and hence cooling from green spaces and water bodies as well as innovative use of alternative building materials in urban areas might help in biodiversity conservation. Numerous studies confirm that green spaces significantly improve air quality, reduce urban heat, and mitigate flood risks through enhanced water regulation through increasing soil percolation (Hobbie and Grimm, 2020; Wang et al., 2021a; Wang et al., 2021b; Zhang et al., 2021). Additionally, green spaces are shown to promote biodiversity and create vital habitats for urban wildlife (Atchadé et al., 2023; Ballinas and Barradas, 2015; Chowdhury et al., 2021; Li et al., 2023). Research from Dhaka, Bangladesh, found that nearly half of the country's butterfly diversity was found in city green spaces, with parks and butterfly gardens providing the most viable habitat (Chowdhury et al., 2021). Evidence from Ethiopia suggests that urban green spaces can be seen as a potential site for biodiversity conservation and climate change mitigation as they often host endangered flora and have significant carbon stock (Muluneh and Worku, 2022).

Socially, urban green spaces with higher level of biodiversity contribute to emotional valence and mental well-being, physical health, and community engagement by offering accessible recreational areas (Gong et al., 2024). Economically, they increase property values in the surrounding areas, attract tourism, and reduce healthcare costs (Bille et al., 2023). Seen together, these findings emphasise the crucial role of green spaces in building resilient, sustainable cities, especially using the spaces surrounding the built environment to create pockets of green habitats in an unsuitable matrix (Ferreira et al., 2021; Rabou, 2019).

Our review of the literature finds that often the first incentive to increase urban green space is not biodiversity management but human health and other co-benefits. However, green spaces serve as recreational and cultural grounds, with climate regulation and food gardens as two major services. Social and ecological justice is deeply woven into the spacing and sizing of urban green spaces, with larger parks often coinciding with richer neighborhoods, while in poorer households, smaller parks are often squeezed between buildings (Bille et al., 2023; McPhearson et al., 2023).

As cities expand, natural habitats are often fragmented or lost, leaving these green spaces as critical refuges for species including birds (i.e. *Cinnyris* spp., *Milvus* spp.), pollinators (i.e. *Apoidae* spp., *Papilionidae* spp.), small mammals (i.e. *Urva* sp., *Macaca radiata*, *Funambulus palmarum*) and insects (i.e. *Coleoptera* spp., *Formicidae* spp.) Urban green spaces serve as essential habitats for wildlife, supporting biodiversity in increasingly developed landscapes (Wolff et al., 2023). Research in Dhaka, Bangladesh, found that certain species of butterflies such as *Leptosia nina*, *Eurema hecabe*, and *Catopsilia pomona*, were frequently recorded across three separate study sites, suggesting that they are relatively tolerant of urbanisation and human activity (Chowdhury et al., 2021). Pollution-tolerant species may also thrive in less-suitable zones, as seen in the Gaza Strip, where bird species like the spur-winged plover (*Vanellus spinosus*) and cattle egret (*Bubulcus ibis*) frequent wastewater treatment ponds and city tanks (Rabou, 2019).

Such green spaces provide food, shelter, and breeding grounds, contributing to the survival of urban-adapted species and also allowing some native species to thrive. By maintaining ecological corridors and connecting fragmented habitats, green spaces promote species movement and genetic diversity (McPhearson et al., 2023). Additionally, they offer opportunities for humans to experience and engage with urban wildlife, fostering environmental stewardship and a deeper connection to nature within urban environments (Atchadé et al., 2023). Incorporating such green spaces into the planning and design of cities is imperative to expand suitable wildlife habitat within an increasingly hostile urban environment. The 3-30-300 perspective, which proposes ease of access to nature in cities with three trees viewable from homes and schools, with 30% canopy cover within a neighbourhood and a maximum of 300m distance to green spaces to provide just green accessibility for all, remains a major challenge in the Global South, particularly in developing economies.

A major challenge in the implementation of urban green spaces is their maintenance, preservation, and conservation. However, studies exploring these broad challenges on scaling up and implementation of urban green spaces are lacking, and they are vital to improving our understanding of green spaces as an effective NbS. Studies from the Global North suggest that, with respect to urban green spaces, the management and stakeholders are rarely consulted, and rarely are the recommendations from academicians considered (Bousquet et al., 2023). When communities are involved, recommendations from communities and academicians should be taken into consideration together to develop green spaces. Studies suggest that this will help in the effective preservation of green spaces and in conserving more biodiversity.

3.1.3. Urban forests

Vegetation tracts that host wildlife and native trees in the city and its periphery comprise urban forests. Urban forests usually comprise native vegetation and host wildlife, they are different from BGI and green spaces as these are usually naturally occurring forest patches located within the city. 12 studies (7 primary and 5 reviews) from our literature review focused on urban forests as an NbS solution. Urban forests encompass vegetation associated with urban areas and peri-urban areas and are the transition zones between urban and rural areas. Urban forests provide refugia and food resources for birds and small mammals in the city, thus helping biodiversity (Soulé et al., 2022). However, there is a mixed response on the services/disservices of urban forests in the literature, as some studies highlight the negative impacts of urban forests, such as uncomfortably close interactions with wildlife often leading to conflict and allergies due to excessive pollen in the air. But restoration of urban forests were reported to help in mitigating the loss of threatened species, ecosystems, and critical habitats (Wudu et al., 2023).

Urban forests are found across many cities in the Global South, but they are often unmapped and underreported (Brunn et al., 2025). Sometimes, these forests comprise native trees, while in other cases, they might be city gardens or parks with forest tracks and might have exotic plant cover (De Carvalho et al., 2022). Using native plant species is beneficial, as these plants are well adapted to the local climate and require less acclimatisation time, and they support other native biodiversity (Abubakar and Alshammari, 2023). The general perception of these studies was that citizens viewed these forests as having a positive influence on quality of life (Takayama et al., 2019). However, it was also clear that the awareness and knowledge of citizens about biodiversity in urban forests was very low (Hooykaas et al., 2019).

However, due to a lack of effective management and maintenance, these forests may be taken over by invasive and exotic species (Potgieter et al., 2017), which will not only degrade the water table and soil quality (Castro-Díez et al., 2021) but may also cause respiratory and allergic conditions in humans (Stevanovic et al., 2025). More research is needed to understand the species composition, species traits, and population dynamics of faunal species that are appropriate for urban forests.

One positive impact of urban forests on wildlife and biodiversity is that they create corridors for species movement and migration by providing connectivity between existing peri-urban or rural natural habitats (Zellmer and Goto, 2022). In India and Nepal, sacred groves and trees offer a necessary buffer against urban environmental stress and serve as refuges for urban wildlife, offering multiple ecosystem services (Pauleit et al., 2021). A study from urban cities in northern China shows that diverse urban forest parks evoke positive and happy emotions, with females and older visitors exhibiting higher positive emotions (Wei et al., 2022). A case study in Mexico demonstrated that to reduce air temperature by one degree Celsius, it took 63 large eucalyptus trees (an exotic species for Mexico) per hectare, whereas the use of sweetgum (*Liquidambar styraciflua*), a native tree species, reduced the temperature by two degrees with just 24 large trees per hectare. This not only increased the number of native species of trees in the region, but also a combination of about four types of native species helped in increasing the local biodiversity by providing the right natural habitat required (Ballinas and Barradas, 2015). Furthermore, the urban forests in Nigerian cities of Port Harcourt and Ilorin store 67,979 and 91,512 tons of carbon, indicating that tree species diversity and selection of the right trees have a significant impact on carbon sequestration (Agbelade and Onyekwelu, 2020).

A few studies in our review indirectly suggest that afforestation fits the definition of NbS and could be considered as an intervention (De Rooij and Van Hattum, 2022), provided that it meets the framework for NbS criteria (Figure 7). The main benefits provided by afforestation are clean air, an increase in the water table, and climate change mitigation. In some instances, afforestation can improve groundwater recharge through enhanced infiltration, while in many other instances it can deplete groundwater through transpiration demands, known as the 'infiltration-evapotranspiration trade-off hypothesis' (Krishnaswamy et al., 2013; Krishnaswamy et al., 2018; Srinivasan et al., 2015; Tuswa et al., 2019). Afforestation activities greatly helped in carbon sequestration (Di Sacco et al., 2021); however, it was recommended to ensure the plantation of native species to promote conservation of local biodiversity and sustained ecosystem services. More detailed studies are required to understand if afforestation can be an effective NbS strategy, particularly if it is made scalable.

3.1.4. Rewilding

Rewilding is defined as bringing back lost species that were once naturally found in an area by means of reintroduction, making it an important NbS and conservation strategy (Lorimer et al., 2015). We found two reviews that focused on rewilding and proposed it as an effective way to conserve native biodiversity. For instance, the reintroduction of some frugivorous birds, such as the common myna

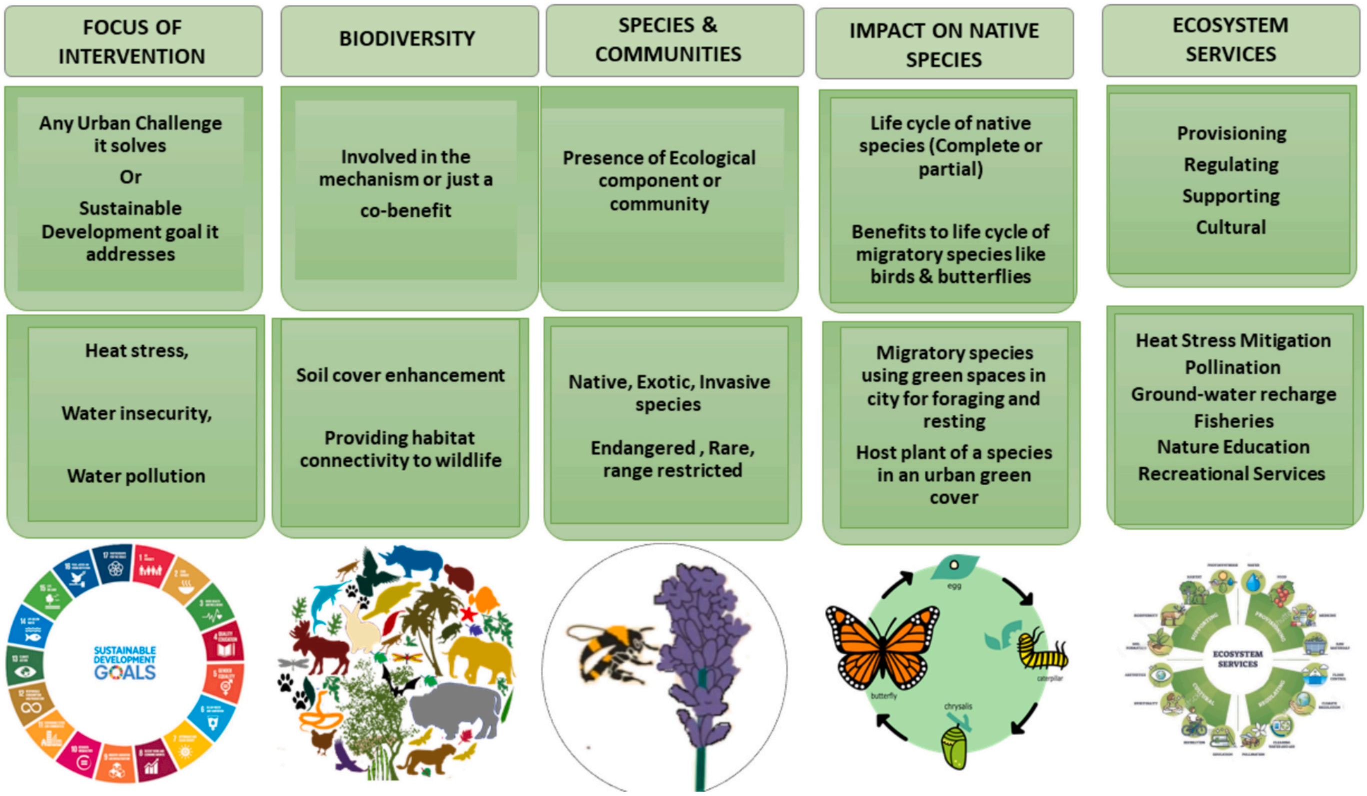

Fig. 7. Framework for assessing contribution of NbS to biodiversity in the Global South. Factors that can be considered while assessing the contribution of NbS intervention for urban biodiversity conservation: a) Urban challenge solved by the intervention and its alignment with Sustainable Development Goals; b) Biodiversity involved as a mechanism or a co-benefit; c) Role of native, exotic, and invasive species and communities as one of the components along with the status of species as endangered, rare, or threatened; d) The impact of NbS intervention on native species to understand whether it helps complete the species life cycle or it benefits migratory species; e) Provision of ecosystem services by the NbS interventions in terms of provisioning, regulating, supporting, and cultural services.

(*Acridotheres tristis*), resulted in increased seed dispersal in a degraded forest (Pollock et al., 2022). This reduced the efforts required for manual seeding and planting of native species, and self-regulating the state of the forest was achieved faster. (Thierry and Rogers, 2020). However, studies caution about the choice of plant or animal species introduced while rewilding, as the use of exotic and invasive plant species can degrade urban landscapes, thereby threatening native biodiversity in the long term.

As the literature had a limited number of studies on rewilding, there wasn't enough information on the gaps and pitfalls when using it as an NbS, and the scalability issue was also not discussed. More in-depth studies are required, as these projects are difficult to implement and sustain in the initial stages, and it is hard to gauge their feasibility. The literature highlights that most of these studies were implemented in suitable habitats for reintroduction, but not where they were needed the most (Thierry and Rogers, 2020). The focus of the rewilding efforts was largely on keystone species of plants or, in the case of fauna, on large mammals, and therefore less conspicuous species are often overlooked. The monetary costs of rewilding are very high. Studies have reported that ecosystems/habitats are generally difficult to rewild with large animals and birds, hence many studies choose plants and smaller invertebrates (Contos et al., 2021). The idea of rewilding with plants, microbes, and invertebrates is that, once habitats are reintroduced with flora and fauna, they will automatically attract other biodiversity (Lehmann, 2021) and restore the ecosystem to its initial or native functioning (Contos et al., 2023). Studies have shown that rewilding-inspired forestry may have higher biodiversity, store more carbon, and improve socio-ecological resilience as it emphasises trophic complexity, natural disturbances, and species dispersal (Wang et al., 2025). Despite the socio-economic challenges and complexity of initial maintenance, rewilding can help in biodiversity conservation through passive means and hence can be considered an effective NbS (Almenar et al., 2021).

3.1.5. *Green roofs*

Green roofs are rooftop gardens and consist of terraces and roofs that have vegetation cover (Besir and Cuce, 2018). Ten papers (6 primary and 4 reviews) have suggested that green roofs as NbS significantly improve urban biodiversity by providing species with habitats and shelter. These flora and fauna include soil arthropods such as Hymenoptera, Diptera, Hemiptera, Thysanoptera and Collembola and worms, as well as many species of birds, spiders, beetles and butterflies. Research indicates that the ecological characteristics of green roofs, such as plant species richness, substrate depth, and roof area, play a significant role in determining the composition and diversity of arthropod communities (Fabián et al., 2021).

The benefits of green roofs are multifaceted, providing a wide array of ecosystem services such as stormwater management, temperature regulation, air quality improvement, and the promotion of urban biodiversity (Calheiros and Stefanakis, 2021). Moreover, green roofs have been shown to improve air quality, mitigate the urban heat island effect through carbon sequestration and reducing energy consumption (Liu et al., 2021), which can in turn lead to a reduction in greenhouse gas emissions, and contribute to urban sustainability by integrating green infrastructure into the built environment. Empirical evidence show that green roofs can offer significant thermal comfort by reducing cooling load by up to 70% and indoor air temperature by up to 15°C, along with improvements in air quality, noise, and carbon sequestration (Mihalakakou et al., 2023). Findings from semi-arid regions show that the ambient temperature dropped from 44.6 °C to 34.7 °C due to green roofs, with a higher cooling effect under diverse plant arrangements

(Robbiati et al., 2022). Despite these benefits, their use in the Global South is limited compared to other parts of the world due to a lack of awareness and understanding of the potential of green roofs as tools for biodiversity conservation and climate resilience in urban areas (Fitchett et al., 2020). Based on information from literature from the Global South, it was seen that the implementation of green roofs is often supported by diverse stakeholders such as schools, universities, homeowners, and urban planners. As NbS, green roofs represent a powerful strategy for enhancing the circularity and resilience of cities. The strategic implementation of green roofs could play a vital role in preserving urban biodiversity, enhancing ecosystem services, and promoting more sustainable and resilient urban development in the face of growing environmental pressures (Barriuso and Urbano, 2021).

3.1.6. Floating wetlands and phytoremediation

Floating wetlands are beds of emergent aquatic vegetation that help in absorbing pollutants (Shahid et al., 2018). In literature, we found only three primary papers discussing constructed wetlands and floating wetlands, and two papers (one primary and one review) on phytoremediation (Figure 3). Phytoremediation is defined as the use of green plants to remove pollutants (Salt et al., 1998). Since the principle of both is the same, i.e., using plants to absorb pollutants from water and increase biodiversity, we have pooled them together under one category. Floating wetlands have been used to counter a wide range of problems, such as uptake of heavy metals, and to filter pollutants. Using artificial floating wetlands can provide habitats to many aquatic organisms such as fish and crustaceans (Huang et al., 2017). For instance, the use of floating wetlands helped in the removal of trace metals from polluted waters of the Ravi River in the city of Lahore; this resulted in an increase in biodiversity and reduced harm to existing biodiversity (Shahid et al., 2018). A study done in South Africa identified native plants that can be used in phytoremediation (Jacklin et al., 2021) and suggested that they were most effective in absorbing pollutants. Literature indicates that using plants for treating polluted water is more cost-effective than other techniques (Yadav et al., 2022). With increasing loss of natural aquatic vegetation, these artificial floating wetlands could potentially help to recreate natural habitats and restore degraded habitats.

Most studies on constructed floating wetlands use macrophytes (aquatic plants growing in the area). They may be free-floating or rooted. There is a lot of variation in the removal of pollutants from the water, and the number of pollutants absorbed varies from species to species (Rigotti et al., 2021). The success of the floating wetland system is highly influenced by the selection of macrophyte species, as a study shows that T. domingensis offered nutrient removal at 4 and 24 hours, while S. californicus showed nutrient removal just for a seven-day batch (Rigotti et al., 2020). Other studies have shown that floating islands have a positive effect on nekton (free-swimming aquatic creatures) diversity, and they also increase habitat availability for other aquatic organisms (Huang et al., 2017). But, like other solutions, a careful selection of plants is advised, as there is a threat of these plants becoming invasive in water bodies. For example, water hyacinth, a widely distributed plant species, is known to absorb heavy metals and pollutants from water bodies but is also one of the world's worst invasive species and affects native biodiversity negatively (Degaga, 2019). Moreover, a case study of floating gardens called Baira, a traditional wetland cultivation practice in Bangladesh, showed that such NbS practice can involve local communities in implementation and management, offering livelihood benefits to vulnerable populations (Lakshmisha et al., 2024).

Some challenges of floating wetlands and phytoremediation include sourcing native plants and seeds, as local nurseries might not have them easily available. Standardised protocols for plant species introduction and data collection on the effectiveness of new plant species can be time-consuming and act as a limiting factor (Freschet et al., 2021). Also, another challenge for these NbS is the inability of plants to regenerate and hence the need for constant monitoring and replacement, which would be cost-intensive (Fletcher et al., 2020).

3.1.7. Quantitative case studies

For some studies where information was available on statistical analysis done, we have used that information to interpret the results and the implications on biodiversity, climate and socioeconomic impacts. We would like to draw the attention of the readers that since most of the studies did not have detailed information on the analysis used and many studies were qualitative and in-depth analysis covering all NbS types across Global South was beyond the scope of this study.

Across the 31 sub-prefectures mega-city of Sao Paulo, Brazil, Surface Heat Island effect was reduced by 3.74 °C for every increase in vegetated area by 1 % (R^2=0.854) (Ferriera et al. 2023). In Mexico City it was found that choice of tree matters for urban heat mitigation. A reduction of 1°C was achieved with 63 large exotic *Eucalyptus camaldulensis* trees per *hectare* whereas to reduce the air temperature by 2°C only 24 large native *Liquidambar styraciflua* trees would be required (Ballinas and Barradas, 2015). Using the data in the study, it is calculated that for twice the cooling effect, the 24 native trees consumed 101 litres of water daily compared to 230 litres by 64 exotic trees. One interesting and novel application of Shannon diversity of tree species was as a predictor of heat stress mitigation in Changzhou, China (Wang et al., 2021a; Wang et al., 2021b). It was found a unit change increase in Shannon's index increased the Temperature Drop Amplitude (TDA) in summer by 2.03, the regression model which also had % tree cover as covariate, explained 57% of the variability in TDA across 15 plots (p=0.003), showing that diversity matters and not just % tree cover. When the tree coverage is kept constant, TDA increases 0.2°C for every 0.1 increase in Shannon-Wiener diversity index

In the Haizhu wetland case from Guangzhou, China, InVEST modelling estimated a cooling effect of 0.25°C within a 600 m buffer and a potential drop of 1.23 % in mortality risk (Guerry et al., 2023). This study took into account humidity and wet-bulb temperature in the modelling.

Quantitative biodiversity data in an experimental design has been used innovatively for comparing performance of native and exotic species of plants in green roofs with respect to two metrics: cover achieved with or without management and number of interactions with pollinators and natural enemies (Calviño et al., 2023). The study found that 40 % of native plants vs 30 % of exotics (p=0.05) remained after one year of establishment with no management but with management it was similar, over 90 %. However native annuals could reseed themselves. In terms of fostering interactions with native arthropods, the advantage of native over exotic plants was scale specific: 4.5 to 12 interactions per 30 minutes for 300 floral units) compared to exotics (below 3 interactions in 30 minutes) (p=0.05). However, at 50 and 150 floral units, this biodiversity co-benefit of native over exotic plants on green roofs was not significant. The green cover achieved was slightly higher and scale effect is particularly relevant as native species were able to produce more flowers than exotics. Overall, with less management and inputs, the advantages of native species in green roofs, especially to help support native arthropods which are declining in cities due to loss of habitat is apparent.

A study from Burkina Faso evaluated the Carbon storage in peri-urban areas (Balima 2023) as a function of tree density, basal area and species richness (R^2 =0.84, p<0.00001). Basal area (m^2 /ha) and species richness (individuals /ha) having a positive impact on carbon storage, whereas tree density had a negative effect (-0.0085, p=0.000017). A unit increase in basal area increased carbon storage by 2.575 Mg /ha (p< 2.00e-16) whereas the effect of species richness was much smaller (0.199 Mg /ha, p=0.0556). Among these variables, stand basal area accounted for 81.80% of the explained variance in carbon storage, tree density accounts for 9.1% of carbon storage variation, while species richness explained only 2% of the variation. The results suggest the importance of tree stand structural variables over diversity.

In a very novel interdisciplinary study, the importance of ethnic composition, biocultural values and colonial history on tree species abundance was analysed using a generalized linear mixed model (GLMM) (Hunte et al., 2019). These 57 species of trees were from different parts of the world and 73% had edible fruits. Their statistical models revealed that distance from the city centre with colonial legacy explained the distribution of some groups of species, while proportion of East Indian residents had weak and variable effects. Several groups of species exhibited a strong positive effect of distance to the city centre indicating that these groups tended to be more abundant further away from the city centre and a few were more abundant closer to the colonial centre. Pan tropical wild trees were more abundant closer to the city centre whereas fruit trees from Africa, Asia and Pan tropics as well as ornamentals from Africa became more abundant away from the colonial centre ($p < 0.05$).

The 55 papers shortlisted in our review included 70 locations that had information for urban area (in km^2), total built-up volume (in m^3), biogeographic zone (Koppen Climate classification) and the green cover. Our analysis revealed an interesting positive regression model relationship between % green cover of the built-up area as a function of city size ($R^2 = 0.1535$, $p< 0.009$) (Figure S5). However, none of the regression models were significant for biodiversity outcomes and urban area, total built-up volume and green cover.

3.2. Framework for assessing contribution of NbS to biodiversity in the Global South

The results from the logistic regression model suggested that presence of at least one ecologist or biologist in the author team positively influenced the ability of the study to report on specific species of biodiversity ($p < 0.05$). The presence of a biologist increased the odds of the reporting of specific species in NbS studies by nearly 5 times (4.98, Confidence interval =1.46 to 20.43) compared to absence. This suggests that inter-disciplinary and multi-disciplinary teams of scholars and practitioners are essential if biodiversity has to be seriously considered in the design and monitoring of NbS.

Out of the 55 papers shortlisted for the review only 16 papers had some quantitative information on biodiversity. In our recommendation standard protocols monitoring biodiversity should be implemented in NbS studies. Basic documentation of before and after comparisons of biodiversity can help in assessment of the effectiveness of NbS for biodiversity conservation and this should be made as a prerequisite for practitioners, researchers and other stake holders while implementing NbS.

The IUCN Global Standard for NbS (IUCN, 2020) provides a framework for users to design NbS in a way that it solves several societal challenges. The framework consists of 8 criteria and 28 indicators that can be used by government offices, NGO's, institutions, and urban planners. Though the framework allows one to effectively assess processes of various projects, it is unable to evaluate the results of the process. The framework does not specifically address environmental contexts and lacks information on resources for assessment. These gaps in the IUCN Global Standard for NbSmay be the reason for its lack of mention in several papers, but the use of this framework along with other established frameworks help bridge the gaps (Le Gouvello et al., 2023; Berg et al., 2024).

The biggest challenge that NBS faces is the lack of knowledge on the systems and the components that are involved in NbS such as the behavior or role of organisms used, or reason for construction of certain structures and their maintenance (Fernandes and Guiomar, 2018). The term Nature Based Solution has been gaining traction in recent times and in the past were used under different names or as specific projects. In order to implement the widespread use of standard terminology for NbS a standard set of terms and typology must be developed (Dushkova and Haase, 2020; Anderson and Gough, 2022).

To assess the efficacy of different interventions as NbS, we have proposed a set of guiding questions for further research (see Box 2). These questions emerged from our syntheses, highlighting the critical gaps in defining and evaluating biodiversity outcomes within the NbS framework. These criteria can help assess NbS for their biodiversity outcomes, specifically the impact of such solutions on native biodiversity. Moreover, some of these NbS could help translate into Other Effective Area-based Conservation Measures (OECMs)—as defined by IUCN as 'areas distinct from traditional Protected Areas (PAs) but managed in ways that yield positive, sustained, and long-term outcomes for biodiversity conservation, including associated ecosystem functions, services, and, when applicable, cultural, spiritual, socio-economic, and other locally significant values' (IUCN), conditional on size and other attributes. This can work as a checklist for donors, practitioners, and project reviewers to ensure that the project qualifies as an NbS both in letter and spirit. Figure 7 shows a visual representation of the interlinkages and themes emerging from these questions, illustrating the framework for assessing the contribution of NbS to biodiversity in the Global South.

3.3. Limitations of our study

Our systematic literature review has some of the following limitations:

1. The review was restricted to only peer-reviewed articles, which might have potentially excluded evidence from grey literature, case studies, and institutional reports and publications.
2. We selected articles published only in the English language, which might have created a language bias resulting in the exclusion of literature published in regional languages in the Global South.
3. The studies define NbS and associated biodiversity outcomes in varied contexts, which might have excluded a few articles where the particular intervention did not specifically mention it as NbS or the biodiversity outcomes were not explicitly mentioned.
4. High spatio-temporal resolution of climate (temperature and precipitation) and other variables (vegetation, soil moisture) can enhance our understanding of NbS and how successful implementation of NbS can contribute to ecosystem services (Lal et al., 2023; Lal et al., 2025). However, in addition to remotely sensed data, there is a need to measure these parameters on the ground as well as their effects on biodiversity through regular in-situ monitoring to evaluate whether other drivers also impact NbS. Both these measurements in tandem can provide us a holistic picture of the NbS and its functioning.

3.4. Gaps in NbS research

Our literature review and synthesis gave insights on how NbS can help in biodiversity conservation. This supports previous findings from NbS across the world that, NbS generally have positive impacts on biodiversity (Li et al., 2025). Most papers find that NbS that use plants as a solution have varied outcomes depending on whether native or exotic species were used. Our assessment of studies that report on urban NbS that address urban challenges or SDGs suggests that the role of native biodiversity as a co-benefit is often either inadequately described or poorly incorporated in the design of the NbS itself. Even in those cases where native biodiversity is specifically involved, the actual support for native biodiversity (e.g., life cycle) is not reported. Apart from providing crucial ecosystem services such as pollination, flood mitigation, and pest control, NbS types such as green roofs and green spaces also provide important cultural services. While some studies mention that rare and endangered species (e.g., olive ridley turtles, migratory birds) are supported by NbS implementations, most of the studies don't mention the exact species that might benefit from the implementation of the NbS. Such information can prove useful in developing wider management and conservation plans with a focus on endangered and threatened species that are of high priority. Most studies focus on biodiversity conservation of trees and plants, but very few studies address conservation of birds and large mammals. This might be one of the limitations of NbS as an urban conservation strategy: that only certain species or groups can be conserved by implementing NbS, but other species might still remain at risk. However, using a variety of NbS can be one solution, as more native species could be targeted. Lastly, despite some studies mentioning the effects of NbS on ecosystem services and SDGs, these are mostly qualitative rather than quantitative measures of how NbS influences various biodiversity, societal, and climate outcomes. Future research must also focus on quantifying these effects in order to improve our understanding of how NbS can serve as natural climate solutions, as well as strengthen the support from various stakeholders for fostering biodiversity conservation.

4. Conclusions

In the Global North, NbS is now a popular concept in the space of climate adaptation and mitigating the urban heat island effect. Populations in the Global South have historically relied on NbS like wetlands and tree cover to manage climate impacts and infrastructure gaps. Moreover, community gardens, open green spaces, and even constructed wetlands, although not labelled as NbS until recently, offer benefits such as food security, ecosystem restoration, and climate resilience. General synthesis indicates that the combination of multiple NbS types may help conserve and even create a larger ecosystem, leading to natural interactions such as pollination, predation, and even scavenging if done properly.

However, the ecosystem services and urban challenges solved by these NbS projects are often articulated with a focus on societal benefits rather than climate mitigation and biodiversity conservation. We have summarised the biodiversity criteria that need to be considered carefully in existing and future NbS projects in addition to the other IUCN criteria of replicability and scale (Figure 7). We highlight limitations and drawbacks of existing NbS (Box 2 and Appendix Table S3) and suggest possible recommendations (Box 3) that can lead to greater creativity in the planning, design, and implementation of NbS that effectively supports native biodiversity at scale. Our results outline the challenges and opportunities for incorporating native biodiversity in designing and implementing NbS in the Global South. In promoting NbS as a solution to problems of pollution, degradation or climate change, it is important to recognize their limitations (Fernandes and Guiomar, 2018). Even natural and semi-wild ecosystems are being impacted severely by extreme events (Jentsch and Beierkuhnlein, 2008) and urban spaces are particularly vulnerable. Extreme events such as over 900 mm of rainfall in a day (Mohanty et al., 2023) or over a 100 mm in an hour (Dimri et al., 2017) are highly likely to overwhelm all semi-natural, NbS or engineered systems. There are concerns over their performance at scale and there is a need to generate evidence on success and failures and to design and implement NbS connected and combined with engineered systems or grey infrastructure in many situations. This may help avoid maladaptation and move towards multifunctional urban landscapes that solve problems and promote native biodiversity (Seddon et al., 2020; Chausson et al., 2020; Ruangpan et al., 2020; Huang et al., 2020; Abera et al., 2025; McPhearson et al., 2025).

Our synthesis also highlights that many studies overlook key ecological dimensions such as functional traits, trophic roles, and species interactions, including pollination networks and predator-prey dynamics. These aspects are crucial for evaluating ecological integrity and resilience of urban ecosystems. Future studies would be strengthened by a broader consideration of how NbS affect ecosystem functionality and ecological connectivity, especially within and between fragmented urban systems.

Going forward one policy frame that may be of relevance to NbS in the global south is related to the innovation and adaptation of indigenous appropriate technology to address biodiversity and ecosystem services conservation. Often, technological solutions supporting NbS implementation may not be cost-effective for the developing world. Here, implementation should make efforts towards the promotion of local innovation in biodiversity conservation by recapitulating and mainstreaming local knowledge and solutions based on experientially accumulated learning. NbS planning in the global south should address problems from a co-benefits framing, including biodiversity conservation, social vulnerability reduction, and Indigenous customs and knowledge preservation (Abera et al., 2025). This can be an important horizon for future creative policymaking to pursue, as the paper indicates.

To summarize, a critical gap exists in the methodology and data surrounding NbS, primarily due to the lack of robust, long-term monitoring and essential baseline assessments to accurately quantify biodiversity outcomes. This is further hindered by deficiencies in policy and implementation, as urban planning often fails to set explicit conservation targets, establish ecological connectivity, or prioritize native species essential for ecological function. Overall, this reiterates the dire need for rigorous studies to improve our understanding of NbS and help inform future NbS design and implementation strategies for the Global South to enable NbS to become an effective instrument for biodiversity conservation.

CRediT authorship contribution statement

Ravi Jambhekar: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Ryan Satish:** Writing – review & editing, Writing – original draft, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation. **Swarnika Sharma:** Writing – review & editing, Writing – original draft, Validation, Resources, Methodology, Investigation, Formal analysis, Data curation. **Gayatri Bakhale:** Writing – review & editing, Writing – original draft, Visualization, Resources, Methodology, Investigation, Formal analysis, Data curation. **Priya Ranganathan:** Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Dilip G.T. Naidu:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation. **Kadambari Deshpande:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Formal analysis, Conceptualization. **Jagdish Krishnaswamy:** Writing – review & editing, Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Acknowledgements

This study acknowledges the support from Agence Française de Développement (AFD) through the research project— “Greening Urban Food Systems: Building Sustainable Urban Agriculture Practices in Bengaluru Through Nature-based Solutions”. We acknowledge the inputs of Chandni Singh during the initial stages of finalizing the keywords for literature search and designing the review process of papers for the manuscript. We are grateful to the IIHS Library team for their help with acquiring papers that were not available in the open access domain. We are grateful for the IIHS Word Lab and Narmada Khare for her inputs and their feedback to help improve the clarity of this manuscript. We also thank Ananya Rao for her inputs in checking the proof.

Declaration of competing interest

All the authors declare no financial or personal relationships that may be perceived as influencing this work. The authors declare no conflicts of interest that affect the integrity of this manuscript.

BOX 1: Search criteria for literature review

"nature based Solution*" OR "biodiversity" OR "urban biodiversity" OR "blue green Infrastructure" OR "green infrastructure" OR "urban greening" OR "urban*" OR "ecosystem Service*" OR "ecosystem*" OR "Pollination" OR "aquatic restoration" OR "ecological restoration" OR "NbS" OR "lake restoration*" OR "tree plantation" OR "forest regeneration*" OR "micro climate" OR "climate change" OR "urban wetlands" OR "Urban parks" OR "Urban garden*" OR "community garden"OR "nutrient cycling"

AND "global south" OR "South Asia" OR "South America" OR "Africa" OR "Middle east"

AND "flora*" OR "fauna*"OR "bees" OR "rewilding" OR "urban forest*" OR "public garden*" OR "Vertical Garden*" OR "green roofs" OR "pollution*" OR "soil*" OR "water" OR "air" OR "sound" OR "heat island" OR "floating wetlands"

Exclusion criteria:

NOT "Meta analysis" NOT "Global North" NOT "Human health" NOT "public health" NOT "Child health" NOT "Child*" NOT "disease" NOT "Health care" NOT "Health"

BOX 2: Outstanding Questions for future Research and assessment of NbS

1. What urban challenge, problem, or SDG does the intervention help solve or focus on?
2. What component or ecological community of native biodiversity belonging to the region is involved in the project?
3. Is native biodiversity involved in the mechanism of the NbS, or is native biodiversity also a beneficiary?
4. Is there a mix of native, exotic, and invasive species of plants and animals at the site?
5. Can the native species of plants and animals complete their entire life cycle in the space occupied by the NbS?
6. Can the native species of plants and animals complete part of their life cycle at the site and the rest in nearby sites?
7. In addition to complete or partial life cycle support for native biodiversity at the site, are there migratory species (e.g., birds or butterflies) that are supported by the site?
8. How many of the species supported by the project are endangered, rare, or range restricted?
9. What type of ecosystem services are linked with the biodiversity components of the NbS at the site?

BOX 3: Practical recommendations

1. A city specific best practice manual and a dynamic portal for incorporating biodiversity in NbS
2. Training and capacity building on biodiversity for NbS for non-ecologists such as engineers and urban planners who are involved in design and planning for NbS
3. Mapping of existing and potential NbS sites in cities to better understand the cumulative impact of NbS across the city on conservation of native biodiversity
4. Understanding the role of non-invasive exotic flora species that support rare, threatened, or range-restricted native fauna in cities and whether such species could be considered as an integral part of NbS on a case-by-case basis.
5. Investment in training for incorporating native biodiversity as part of NbS project design and implementation
6. Partnerships among government agencies, NGOs, academia, private sector and civil society for regular monitoring of biodiversity outcomes over space and time and learn from successes and failures
7. Only a subset of NbS may be considered for recognition as other effective area-based conservation measures (OECMs) where conservation of biodiversity is achieved as a co-benefit of land use outside protected areas, and this needs to be done carefully; otherwise it may overestimate achievement of conservation targets and goals.
8. Research on which species can thrive in the city and how can we redesign NbS to support more native species (eg. Patankar et al., 2021). Other effective area-based conservation measures (OECM) where conservation of biodiversity is achieved as a co-benefit of land-use
outside protected areas offers opportunities for linking Sustainable Development Goals for
cities to national and global ecosystem and biodiversity conservation targets (e.g. Jambhekar
et al 2025).
9. Interdisciplinary and multi-disciplinary assessments of NbS that includes at least one
ecologist who can understand and describe the biodiversity and ecological dimensions of

(*continued on next column*)

(*continued*)

specific NbS projects.
10. Partnerships among governments, NGOs, academia, private sectors, local communities,
and financial sectors to jointly develop and implement NbS projects may result in fewer
trade-offs and maladaptation or ecological injustice.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolind.2026.114627.

Data availability

The data has been submitted as Supplementary material.

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