



Effectiveness of nature-based solutions to address water challenges in the Greater Mekong Subregion: a systematic mapping

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ABSTRACT

The Greater Mekong Subregion (GMS) faces escalating water-related challenges, including floods, droughts, sea-level rise, and coastal erosion. Nature-based Solutions (NbS) offer a promising approach to address these challenges, yet their long-term effectiveness is difficult to evaluate and remains under-monitored, limiting policy uptake. This systematic mapping reviews scientific evidence from 2012 to 2023 on NbS implemented for water challenges in the GMS. Findings reveal a regional imbalance, with most studies in Vietnam and Thailand, and limited representation in Myanmar, Lao PDR, and Cambodia. NbS interventions most documented include mangrove protection or restoration (13 %), forest protection or restoration (13 %), and wetland creation or restoration (11 %). Coastal protection (31 %) and flood management (25 %) are the primary challenges addressed, while fewer studies focus on water quality, storage, or supply. About half of the studies assessed multiple outcomes; 33 % focused only on ecological outcomes, with fewer examining social (14 %) or economic outcomes (9 %), though co-benefits such as recreation and thermal comfort were noted. Over half of the studies (55 %) met criteria for socioeconomic benefits, sustainability, natural resource conservation, and multi-functionality, while 45 % did not fully address these. Research gaps remain in underrepresented countries and less-studied outcomes, including the role and implications of revitalizing traditional knowledge within NbS framework, highlighting the need for more comprehensive evaluation to support integration of NbS into national and regional water management strategies.

1. Introduction

Nature-based solutions (NbS) have emerged as a transformative approach to address interconnected societal and environmental challenges such as climate change, water security, and biodiversity loss [1, 2]. The United Nations Environment Assembly (UNEA) has defined NbS: “Nature-based solutions are actions to protect, conserve, restore, sustainably use and manage 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,” [3]. Within water sector, NbS interventions can function at both landscape and site-specific scales. At the landscape scale, they involve the creation, management, protection, and restoration of natural ecosystems such as wetlands, forests, and floodplains to mitigate flooding, enhance water

storage, regulate water quality, and improve ecosystem health [4–7]. At the site-specific scale, interventions include blue-green infrastructure such as constructed wetlands, green roofs, and furrows. They contribute to water management and quality improvement [8,9]. Global policy frameworks have been increasingly embedding NbS, including the Paris Agreement [10] and the Sendai Framework for Disaster Risk Reduction [11]. Regional and national strategies also integrating NbS and Ecosystem-based adaptations (EbA) into water and climate interventions. For example, the ASEAN State of Climate Change Report [12] and Nationally Determined Contributions (NDCs) of Mekong countries identify NbS as potential measures for climate adaptation, though commitments vary [13]. The Mekong River Commission (MRC) Basin Development Strategy largely recognizes the values of ecosystems and promotes ecosystem-based approaches, however implementation remains limited [14] and the MRC’s state of the basin report (2023)

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emphasized nature-based solutions for water security [15].

The GMS region include Cambodia, Yunnan Province and Guangxi Zhuang Autonomous Region of People’s Republic of China, Lao People’s Democratic Republic, Myanmar, Thailand and Viet Nam. In the region, water is one of the most contested natural resources, under pressure from rapid urbanisation, agricultural intensification, hydropower expansion, and climate change [16–18]. Despite abundant water resources, the region faces recurrent floods, droughts, coastal erosion, and pollution, with extreme events such as storms and floods causing significant socio-economic losses. In the Lower Mekong, average flood damage costs between 2010 and 2014 was US\$ 0.2 billion annually [19], while water resources are also polluted by the aquaculture and agricultural runoff [20,21] and untreated municipal wastewater [22]. The MRC’s State of the Basin Report (2018) highlights urgent concerns, including reduced sediment flows and wetland loss—issues that directly undermine NbS effectiveness [19].

Evidence from the Global North demonstrates that NbS interventions, such as wetland restoration, reforestation, and blue-green infrastructure, can effectively mitigate floods, enhance water retention, and regulate water quality [23,24]. For instance, studies in Europe and North America have shown that constructed wetlands and riparian buffer zones contribute to nutrient retention and flood control while providing co-benefits for biodiversity and recreation [25,26].

Despite this potential, the implementation of NbS in the Global South, including the Mekong Region, faces several challenges. Limited data on the extent of current adoption, insufficient guidelines for project development, and a lack of rigorous scientific assessments hinder their integration into regional and national water management strategies [27]. Recent reviews have highlighted that peer-reviewed scientific literature on NbS effectiveness remains sparse, particularly in developing countries [28–30]. This knowledge gap constrains policymakers and practitioners in making evidence-based decisions for mainstreaming NbS into climate adaptation and water security strategies [31,32]. Despite global recognition of NbS, their implementation and policy uptake in the Greater Mekong Subregion (GMS) remains limited, hindered by lack of technical capacity, financial and institutional constraints [33,34].

NbS offers a sustainable means to address regional water challenges in the Mekong by integrating ecosystem-based strategies with existing infrastructure and governance frameworks [35,36]. However, to facilitate broader adoption, a clearer understanding of their effectiveness in diverse hydrological and socio-economic contexts is needed.

Therefore, this study performs a systematic mapping of NbS interventions implemented to address water challenges in the Mekong Region. The review intends to delineate the current state of evidence on NbS effectiveness including the type of NbS applied, water challenges addressed and the effectiveness of these solutions. The effectiveness of NbS includes environmental, physical, social and economic elements [37] along with its capacity to deliver multiple co-benefits [38]. This review addresses the following research questions:

- i) What is the current state of research on NbS in the Mekong Region?
- ii) What types of NbS intervention are applied and which water challenges are targeted?
- iii) What are the reported co-benefits and level of effectiveness of NbS interventions

2. Methods

2.1. Literature review

This study employs a systematic mapping approach to map the evidence of the effectiveness of Nature-based Solutions (NbS) in addressing water-related challenges in the Greater Mekong Subregion (GMS), covering Yunnan and Guangxi region of China, Cambodia, Laos,

Myanmar, Thailand, and Vietnam.

The systematic mapping adhered to the framework and guidelines from James et al. [39], which outlined transparent and repeatable stages and specific considerations for each stage relevant to conducting systematic mapping in environmental sciences. We also referred to the methodology from Chausson et al. [28], especially for data analysis and mapping stage. In evidence synthesis, the widely used terminology to define key elements is stated as PICO or PECO - Population, Intervention (or Exposure), Comparator and Outcomes [40,41]. Table 1 describes the key elements of the research questions defined for this review. These components were used as search criteria.

Literature search focused on peer-reviewed and grey literature on the NbS applications in the GMS, in academic databases - Scopus and Web of Science and websites, from 2012 - 2023. The search terms previously developed by Dick et al. [42] to capture NbS were adopted and fine-tuned by testing on both bibliographic databases and the search terms to cover the core attributes of water related challenges were added. Additional grey literature search was carried out focusing on websites that collate NbS case studies and/or organizations’ websites that implement the solutions as described in Table 2.

Search strings:

Search string applied in Web of Science.

Web of Science
ALL=((("nature based" OR "nature-based" OR "nature based solution*" OR "nature-based solution*" OR "NBS" OR "ecosystem-based adaptations" OR "EbA" OR "co-benefits" OR "building with nature") AND (hydrology OR flood OR drought OR coastal OR "sea level rise" OR "SLR" OR groundwater OR "water" OR "natural disaster" OR "disaster risk reduction" OR "disaster risk*" OR drr OR hazards OR "Climate change") AND ("Thailand" OR "Vietnam" OR "Cambodia" OR "Myanmar" OR "Lao PDR" OR "Mekong" OR "lower Mekong" OR "Mekong delta" OR "Lancang-Mekong" OR "Yunnan" OR "Guangxi"))

Search string applied in Scopus.

Scopus
TITLE-ABS-KEY ("nature based" OR "nature-based" OR "nature based solution*" OR "nature-based solution*" OR "NBS" OR "ecosystem-based adaptations" OR "EbA" OR "co-benefits" OR "building with nature") AND TITLE-ABS-KEY (hydrology OR flood OR drought OR coastal OR "sea level rise" OR "SLR" OR groundwater OR "water" OR "natural disaster" OR "disaster risk reduction" OR "disaster risk*" OR drr OR hazards OR "Climate change") AND TITLE-ABS-KEY ("Thailand" OR "Vietnam" OR "Cambodia" OR "Myanmar" OR "Lao PDR" OR "Mekong" OR "lower Mekong" OR "Mekong delta" OR "Lancang-Mekong" OR "Yunnan" OR "Guangxi")

To ensure a rigorous and transparent review process, this study follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework [43,44]. PRISMA is a widely used method for systematic reviews that enhances the clarity, reproducibility, and comprehensiveness of the literature selection process. The review process involved four key stages: (1) Identification, where relevant studies were collected using predefined search terms; (2) Screening, where duplicate records and irrelevant studies were excluded based on title and abstract; (3) Eligibility, where full-text articles were assessed against inclusion and exclusion criteria; and (4) Inclusion, where studies meeting all criteria were selected for in-depth analysis.

The PRISMA flow diagram (Fig. 1) is used to document the number of records at each stage, ensuring transparency and replicability. The

Table 1
PICO elements of the question.

Population	Intervention	Comparator	Outcome
Greater Mekong Subregion (GMS)	Implementation of NbS to improve the aspect of water resource management	With or without NbS/ Before and after NbS	Improvement in targeted aspects of water challenges

Table 2

Grey literature data sources and search strategy.

Website	Search strategy
The Global Program on Nature-Based Solutions for Climate Resilience (GPNBS)	Filter by Language (English) AND Region (East Asia & Pacific) and manual browsing
Nature-based Solutions Knowledge Hub	Filter by Region
The Nature-based Solutions Initiative (NbSI)	Filter by Case studies AND Country (Cambodia, China, Laos, Myanmar, Thailand, Vietnam)
Partnership for Environment and Disaster Risk Reduction (PEDRR)	Filter by Virtual Library AND Region (Asia Pacific) AND Hazard Types (Floods, Droughts, Landslides, Storms, tropical cyclones and hurricanes, Tsunamis, Sea level rise, Climate Change, Land degradation, Soil erosion, Other, Not applicable)
PANORAMA – Solutions for a Healthy Planet	Filter by Region (East Asia, Southeast Asia) AND Theme (Climate change, Ecosystem conservations)
Nature4Climate	Filter by Case studies AND Country (Cambodia, China, Laos, Myanmar, Thailand, Vietnam)
OPPLA	Filter by Case studies AND Country (Cambodia, China, Laos, Myanmar, Thailand, Vietnam)
WeADAPT	Filter by Case studies AND Location
CARE climate justice center	Filter by Countries (Cambodia, Laos, Myanmar, Thailand, Vietnam) AND Themes (Disaster Risk and Humanitarian Actions, Ecosystems and Nature-based Solutions)
Cities with nature	Manual Keyword Search (Nature-based Solutions) AND Country
IUCN	Keyword search (Nature based solutions) Filter by year: 2012 - 2023
The International Partnership for the Satoyama Initiative (IPSI)	Filter by Case studies AND Country (Cambodia, China, Laos, Myanmar, Thailand, Vietnam)
Myanmar climate action network	Manual Keyword Search (Nature-based Solutions, Ecosystem-based Adaptations)
PreventionWeb	Key word search (Nature-based Solutions, Ecosystem-based adaptation)
UN habitat Myanmar	Filter by Publication and Manual search

diagram is generated by using the PRISMA Flow Diagram tool [45]. In terms of peer-reviewed literature, the database search across Scopus and Web of Science yielded 255 records based on predefined search terms related to NbS and water challenges in the GMS. Duplicate removal was done in CADIMA software [46] and double check in Zotero software. After removing 64 duplicates, 191 unique studies remained for screening. Titles and abstracts of the 191 studies were assessed for relevance. Studies that were not directly related to NbS, did not focus on the GMS were excluded. After this stage, 26 papers were deemed relevant for full-text assessment. Full-text screening was conducted based on predefined inclusion and exclusion criteria in (Table 3), focusing on studies that explicitly assessed NbS interventions and their effectiveness in water management. As a result, 4 papers were excluded due to insufficient data, or lack of relevance. Finally, 22 studies met all criteria and were included in the systematic review for qualitative and quantitative analysis. Grey literature search yield 92 search results, of which 79 reports were retrieved and screened for more information, with 18 reports passed for eligibility. Combining peer-reviewed and grey literature, the total of 40 papers were included for final analysis.

2.2. Effectiveness criteria

The effectiveness of NbS not only depends on bio-physical criteria but on also their contribution to biodiversity and ecosystem health, socio-economic improvements, and long-term sustainability [38]. To assess the effectiveness of NbS interventions implemented, we referred

to the following effectiveness criteria proposed by Okello et al. [47], and adapted from Maiolo and Pantusa [48].

Criterion 1 – Socio-economic impacts: It concerned socio-economic contributions of the NbS interventions. The impacts can be economic growth, resilience, health and safety of communities. The criterion assessed how NbS contributed to improved resilience to water-related disasters such as floods, droughts, and water pollution. For example, the improvement of communities' resilience to drought by enhancing or increasing their income during the dry season.

Criterion 2 – Sustainable use of natural resources: This criterion focused on the sustainable use of natural resources in designing/ implementing NbS interventions, with optimized usage, minimal waste and reduced pollution. Examples of approaches are building flood retention areas and water storage areas such as furrows, rain-water harvesting and wetland restoration.

Criterion 3 – Conservation of natural resources and regulating services: This criterion analyzed contributions of NbS to conservation of natural resources such as forests, wetlands, and rivers, regulating hydrological cycle, purifying water and supporting biodiversity.

Criterion 4 – Adaptability and multifunctionality of NbS infrastructure: This criterion addressed the adaptability and multifunctionality of NbS infrastructure to changes in environment and socio-economic conditions like climate change, land use changes and population growth. The criterion also accounted for the multi-benefits of NbS such as recreational value while addressing water issues.

The assessment for these criteria was done in a simple rating system with “yes” – if studies discussed qualitatively or quantitatively any of the aspects in the criteria, “no” – if the study did not discuss or the criteria were out of the study's scope. This rating system was chosen to facilitate the ease of data analysis and to capture a broader trend across studies.

2.3. Coding and analysis

Data extraction from the selected studies (both peer reviewed and grey literature) was carried out in excel, and the following data was retrieved and categorized: metadata (title, author, publication year); location of NbS implementation (country); typology of NbS implementation (ecosystem types, intervention types); targeted water-related challenges; reported outcomes; and co-benefits.

Data analysis was undertaken in excel based on the extracted data using descriptive statistics. This entailed cataloguing the number of studies by publication year and country to discern regional trends. The categorized data were summarized using frequencies and percentages to elucidate the context of NbS studies in the region, including the water challenges addressed, the prevalence of various interventions, and the outcomes of these interventions. The data were visualized using Excel and the Flourish Studio platform to facilitate comparison and emphasize significant trends.

2.4. Limitation

The study focused on peer-reviewed articles and grey literature published in English language, excluding the regional languages at this stage. The exclusion of studies in regional languages may lead to under-representation of NbS implemented and evaluated in regional languages. Future reviews may widen their scope by including literature in those regional languages.

3. Results and discussion

3.1. Current state of NbS implementation in the GMS

The upward trend of studies on NbS (Fig. 2) indicates a growing research interest in NbS as a response to water-related challenges in the

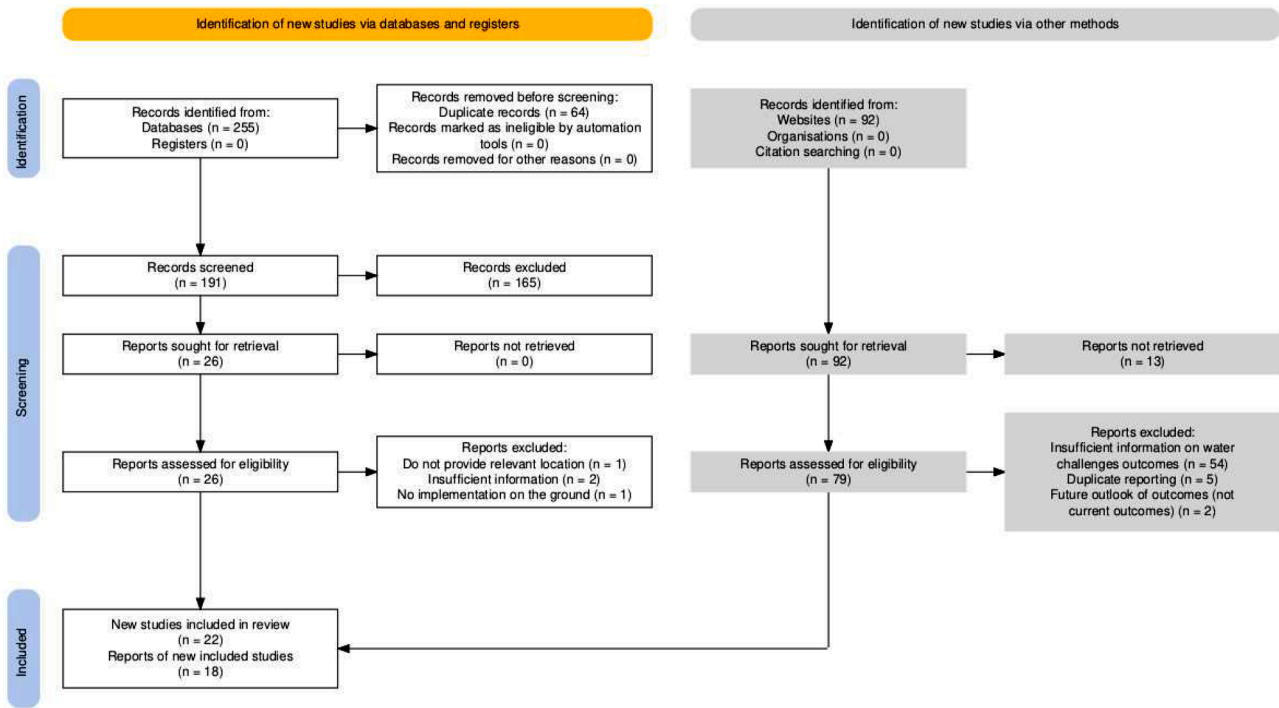


Fig. 1. The PRISMA flow diagram of the process.

Table 3
Inclusion and Exclusion Criteria.

Criteria	Included	Excluded
Publication type	Peer-reviewed papers, grey literature	blogs, news articles, press releases
Geography	Greater Mekong Subregion - Cambodia, Yunnan Province and Guangxi Zhuang Autonomous Region of People's Republic of China, Lao People's Democratic Republic, Myanmar, Thailand and Viet Nam (GMS) (according to ADB)	Countries other than GMS
Language	English	Any other language
NbS typology	Implementations on the ground Studies of existing NbS Case studies implementing NbS assessment frameworks Scenario modelling for case study sites in the GMS	Decision making frameworks which are not applied to case studies sites Selection of NbS for a specific area but no implementation Laboratory experiments which are not implemented on the ground
Water challenges	NbS that aims to address one or more water related challenges (floods, droughts, water quality, water storage, soil and coastal erosion, water access, etc.)	NbS that aims to mitigate GHG emission or that focus only on biodiversity

region. Despite this increase, the total number of peer reviewed articles remained relatively low, suggesting that the research area is still developing and highlighting the need for more extensive research on NbS across GMS. The observed increase in publications may relate to increased global and regional recognition of NbS as a key strategy for mitigating the impacts of climate change, biodiversity and water security challenges [3,13,28]. However, NbS effectiveness is seldom evaluated over longer time periods. The literature from EbA projects implemented over a long term often reiterated the importance of effective monitoring and evaluation [49].

Fig. 3 highlights a clear disparity in NbS research among GMS countries, despite the underrepresented countries, Lao PDR and

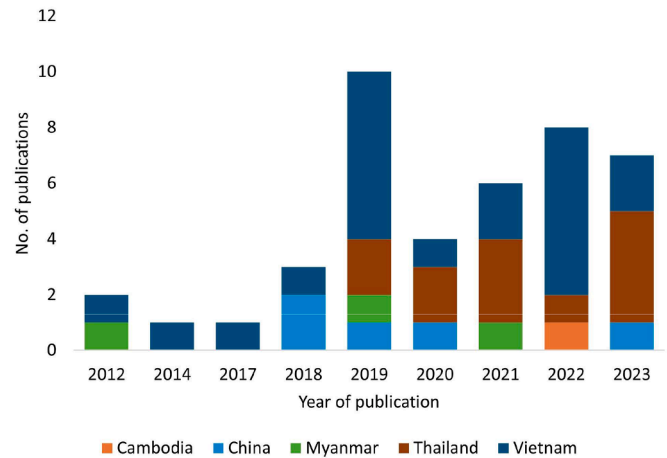


Fig. 2. Trend of literature on NbS for water related challenges in the GMS countries.

Cambodia, being highly vulnerable to climate change, floods and water scarcity [50–52]. Being one of the most productive deltas [53], the Vietnamese Mekong Delta (VMD) received the most attention. The limited literature focusing on other GMS countries could be attributable to lack of baseline hydrological data, climate data, ecological data and socio-economic data which is essential for scientific studies [54]. Additionally, there is a lack of enabling environment for research including lack of finance in water management [55]. Also, in upper middle-income countries like Thailand and Vietnam, have more established research infrastructure and greater access to funding which are the key factors facilitating increased research interest in NbS for water management. For instance, in Thailand, the growing no of studies on NbS could be attributed to initiatives such as the Royal Initiative Project, which have for long support sustainable agricultural practices and environmental conservation [56,57]. In Thailand's extensive research on Nature-based Solutions (NbS), three out of eleven identified studies

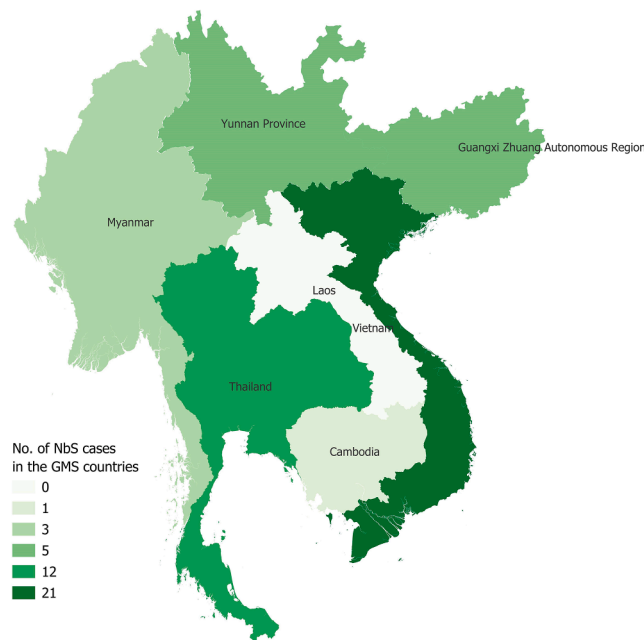


Fig. 3. Geographic distribution of published literature by country.

focus on the use of furrows and monkey cheeks for irrigation purposes. NbS research and implementation in Thailand and Vietnam have also been facilitated by its adoption within their Nationally Determined Contributions (NDCs) and wider acceptance of EbA to address water challenges [58]. Although China has implemented and published the evidence of NbS in other parts of the country [59], only five of NbS published studies in English that address water related issues was found in the GMS region of Yunnan and Guangxi.

These disparities in NbS implementation are not limited only to the GMS. Similar patterns have also been observed in other regions, especially in the Global South. For example, in Sub-Saharan Africa, countries like Kenya, South Africa, Nigeria and Tanzania are significantly advanced in terms of NbS research and implementation [5]. The key facilitating factors are identified to be a bigger economy, stronger educational and research institutions [5]. Similarly in the Andean region (represented by Colombia, Ecuador, Peru, and Bolivia), 75 % of research and publications are from Peru and Ecuador while Colombia and Bolivia represent only 25 % of published literature [60].

These limited research outputs in English from underrepresented countries in the GMS indicate gaps in scientific evidence. We noted that this could also be partly attributable to the exclusion of non-English literature in this study. Additionally, in Laos and Cambodia, REDD+ policy and programs are being implemented, however the outcomes mainly target emission reduction. Thus, they are not captured in our systematic mapping that specifically focuses on NbS for addressing water challenges. The lack of localized studies may indicate a deficiency in knowledge resources and guidance tailored to specific regions leading policymakers to rely on findings from other regions, such as the EU where guidance and evidence is well-established [61]. Nonetheless the evidence from countries in global north may not be fully relevant to the distinct ecological and socio-economic contexts of the GMS. Given that NbS are highly context-specific [62], more scholarly contributions and case studies from the GMS region are needed. These geographical imbalances also mirror broader governance challenges identified at the regional level. For example, the Mekong River Commission's basin planning and adaptation assessments [14] point to unequal distribution of knowledge and capacities among Mekong basin countries. This can then constrain their ability to generate and apply evidence on NbS. While acknowledge that our study only included English language literature, the scarcity of peer-reviewed studies from these countries

therefore, to some extent, may reflect academic gaps as well as potential governance and capacity gaps that shape knowledge production across the region.

3.2. Typology of NbS in the GMS

3.2.1. Types of NbS in the GMS

Fig. 4 maps the NbS for water challenges that have been implemented or studied in the region. A considerable body of literature focuses on creation, restoration and protection [63–65]. Ecosystem protection/restoration includes forest protection/restoration, wetland restoration, and mangrove protection/restoration - the most widely documented NbS. Mangrove ecosystems are among the most degraded ecosystems [66,67] and their restoration and rehabilitation have been a focus in delta and coastal areas. However, the review found that the scholarly contributions examining the effectiveness of these interventions remain limited. This limitation highlights the need for more research on the role of mangroves as NbS within the GMS. The second most documented is structural NbS such as bamboo fences, riverbank restoration. The most recurring NbS – mangrove protection/ restoration, and bamboo fences, predominantly implemented in coastal areas of Vietnam, enhance coastal protection by reducing wave heights, enhancing accumulation of sediment and/or creation of favorable environment for mangrove rehabilitation and growth [68–71]. This may imply that enabling National policies, such as the Mekong Delta Development Plan 2013, contribute to the implementation of NbS in Vietnam. Implementation of hybrid solutions, for example, combination of mangrove restoration, bamboo fences and with hard infrastructure such as concrete breakwater has also been limited to coastal areas. This further substantiates the increased effectiveness of NbS when implemented in combination with traditional grey infrastructure [72]. Penny et al. [73] opined that flood risks are significantly reduced when multiple interventions, including wetland restorations and afforestation/reforestation, are implemented in conjunction.

Urban green infrastructures (UGI), living weir, water-woods restoration and agricultural practices such as furrows, changing farming techniques, contouring, terracing. In the GMS, wetlands are essential for water management and enhancing flood resilience [74]. Urban green infrastructures (UGI), encompassing green roofs, pervious pavement, urban green spaces, rain gardens, urban drainage canals, are integral parts of Water Sensitive Urban Design (WSUD) and are employed to address urban flooding in the GMS [75–77].

The very limited documentation of hybrid NbS, small-scale household level interventions, and combinations of multiple NbS measures suggest not only a research gap but a potential implementation and recognition gap. The small-scale interventions, often locally driven or embedded within everyday water management practices, tend to fall outside formal project reporting. Their underrepresentation indicates untapped opportunities to explore adaptive, locally grounded NbS configurations that may already exist in practice but remain unrecognized in policy and academic discourse. The combinations of multiple NbS are largely studied in scenario modelling studies, which allow to render large scale scenarios such as watershed or basin while their on-ground implementation and monitoring need substantial financial investment, technical expertise and complex governance structure.

3.2.2. Types of NbS outcomes

One-third-of the studies evaluated the physical outcomes of the interventions (e.g. sediment accumulation, water level reduction, wave height reduction, flood water level reduction). The studies evaluated only social outcomes (e.g. recreation, health and well-being), and only economic outcomes are considerably less compared to those evaluated biophysical outcomes. Majority of the studies evaluated multiple types of outcomes, such as a combination of biophysical and social outcomes or social and economic outcomes.

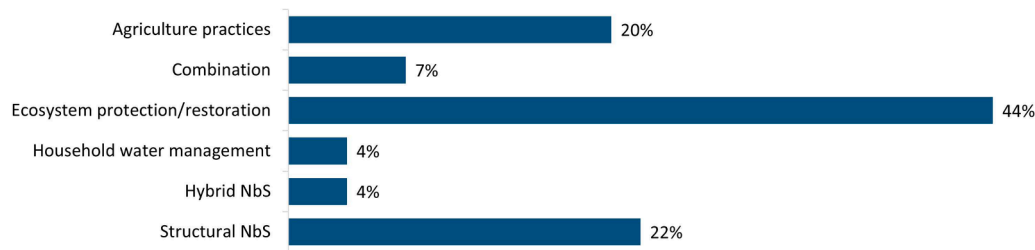


Fig. 4. Types of NbS in percentage of the total number of cases. (Note: No. of NbS exceeds no. of studies as some studies examined more than one NBS type).

The holistic approach where the studies assess multiple indicators – floods, irrigation, water quality, etc. is mainly reflected in the development and application of assessment frameworks of existing interventions such as furrows and floating wetlands, and literature reported in livelihoods opportunities of ecosystem restorations such as mangroves and forests. These studies look at multiple outcomes – biophysical, social and economic. These studies are crucial for providing a more comprehensive understanding of the interventions, as they assess the wide array of benefits beyond the primary objective of the interventions such as reducing flood risks (Fig. 5).

Majority of studies focusing on biophysical outcomes apply scenario modeling rather than empirical assessment. While empirical studies provide direct observations of NbS performance in real-world conditions, scenario modeling plays a crucial role in assessing the impact of combinations of multiple NbS interventions or hybrid interventions at basin or city scales [64,77]. Additionally, scenario-based studies can assist policymakers compare alternative strategies and optimize NbS design by simulating trade-offs between flood risk reduction, ecosystem services, and land-use changes [78]. However, relying on modeling alone may overlook site-specific social and governance factors that influence real-world implementation and success. Therefore, a combination of empirical validation and scenario modeling is necessary to ensure robust, evidence-based decision-making for NbS implementation in the GMS [79].

3.3. Water challenges addressed

Coastal protection constituted the primary water challenge, (Fig. 6), highlighting the significance of coastal and deltas ecosystems in the region. Floods were the second most important water-related challenge that has been addressed in the GMS highlighting the severity of floods. Major river basins in the Mekong Region are facing increased flood risk and heightened vulnerability, such as the Irrawaddy basin in Myanmar

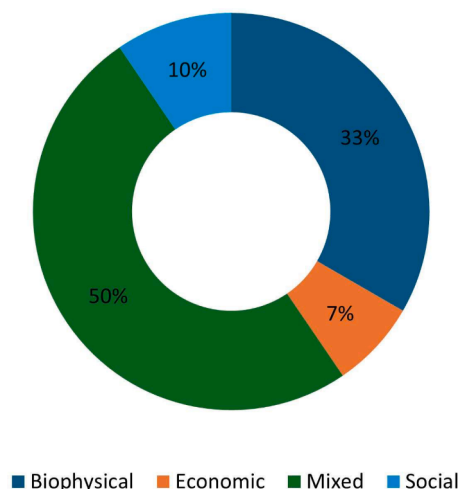


Fig. 5. Types of outcomes assessed by studies.

[80], and several river catchments in Laos [81,82]. The higher cognizance for coastal protection underscores the imperative to safeguard coastal areas in the GMS with deltas shrinking due to sediment deficit attributable to upstream dams, sand mining, sea level rise [83] coastal development, and climate change [84,85]. Over 50 % of the Mekong delta shoreline has been affected by large-scale erosion between 2003 and 2012 [84].

Despite significant water quality issues in the Mekong Region, our review found that very few studies addressed this issue. Elevated salinity levels, pathogenic bacteria and excessive nutrients have been contributing to degrading water quality in rivers [86]. The limited number of cases may be associated with the challenges in implementing and monitoring water quality improvements through NbS, due to the complexity of the natural systems [87] and/or a lack of prioritization of water quality in research agendas. This finding aligns with limited emphasis on water quality improvement through NbS in other regions, such as Africa, where only 3 % of NbS for water management addressed water quality [47]. However, the limited attention to this issue suggests that more targeted studies are needed to explore scalable NbS interventions for water quality improvement.

Only a few studies focused on soil erosion, water storage, and water supply related challenges. NbS including water harvesting and enhancing reservoir storage by mitigating sediment influx through restoration have been studied to improve water availability and storage [88,89]. Challenges such as extreme weather events (such as heat waves, cold snap, etc.), were also less focused in the region. Other water challenges such as groundwater recharge were not emphasized in NbS studies in the region. Watkin et al. [90] proposed a comprehensive assessment framework for furrows which includes indicators on groundwater recharge. However, the study deemed the assessment irrelevant due to insufficient data and assessment methods.

3.3.1. Linkages between NbS interventions, ecosystems and water challenges

Fig. 7 illustrates the linkages between NbS types, ecosystems and water challenges. Mangrove protection/ restoration and bamboo fences were primarily utilized in coastal and delta areas to safeguard the shoreline by reducing wave strength while providing livelihoods opportunities for the communities. Restoring coastal forests with native species was practiced to build community resilience to climate change such as sea level rise and coastal erosion. Flood management interventions primarily include furrows, forest protection, wetlands and urban green infrastructure. Integration of multiple types of NbS types including forest protection and wetland restoration, alongside various forms of UGI such as bioretention, rain gardens or drainage canals have been associated with diverse ecosystems, such as deltas and urban areas, to address multiple water challenges. The exploration of combining one or more types of NbS was primarily conducted through scenario modelling or a mixed approach, wherein certain aspects of the study were evaluated using empirical data, including survey data [64,71,75,77]. Some of the NbS addressed more than one water challenge, for example, furrows serve to mitigate both floods and droughts by improving soil moisture retention, thus contributing to enhanced incomes of agricultural communities, thereby increasing their resilience to

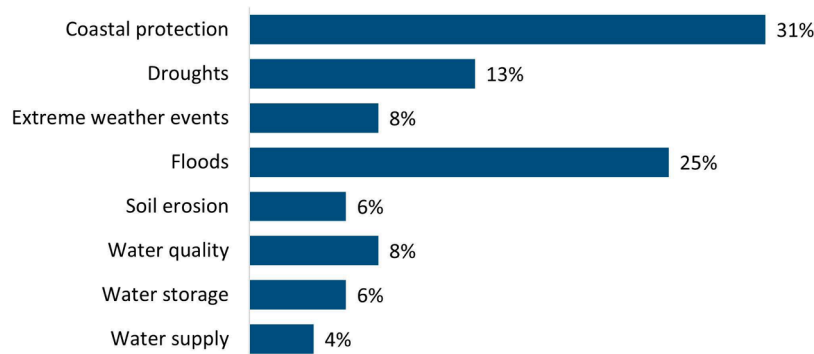


Fig. 6. Water challenges addressed by studies (Note: No. of water challenges exceeds no. of studies as some studies address more than one water challenge).

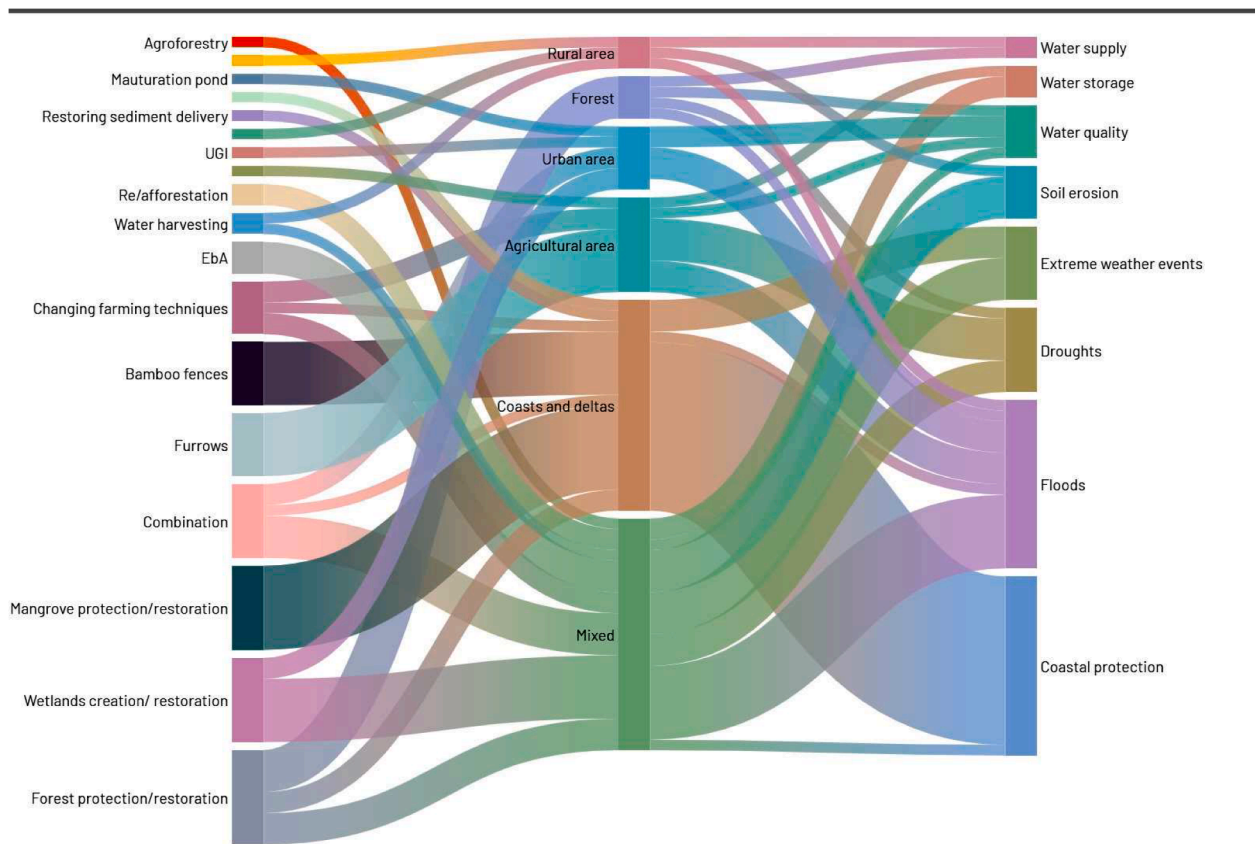


Fig. 7. Linkages between NbS types, ecosystems where they were implemented or modelled, and water challenges addressed. (Note: The width of the line represents the frequency of the studies where these interventions are identified).

droughts. They also improve water quality through infiltration and provide water supply by storing flood waters [91]. Apart from mitigating floods, wetland creation/restoration such as floating wetlands were also considered in addressing water quality and reducing sedimentation [63,65].

3.3.2. Impact of NbS on water challenges

Outcomes of the NbS intervention in addressing water challenges are analyzed in comparison to scenarios without intervention's scenarios and those utilizing conventional grey infrastructure (Fig. 8). Positive outcomes indicate that the NbS enhances the management of the biophysical, social and economic aspects. Mixed results refer to the studies that demonstrated positive outcomes in certain aspects while exhibiting negative or unclear findings in others. Unclear results occur when studies reported ambiguity in their findings or lack sufficient evidence to

determine whether the outcomes are positive or negative or unchanged in comparison to no intervention. Most NbS demonstrated positive outcomes for the challenges they addressed. However, they also present challenges. For instance, a scenario modelling of various NbS types and their combination to reduce flood risk indicated that at basin scale, wetlands alone do not significantly reduce risk. In contrast, wetlands situated near floodplain areas show a significant reduction in risk [64]. The solutions were most effective when various NbS types were combined rather than implementing one. Other studies on flood risk reduction emphasize that the most effective scenarios involve a combination of NbS and advanced technologies, such as real-time control systems, or integration with grey infrastructure. Additionally, enhancing connectivity between NbS practices, such as urban green infrastructure, is crucial [75,77,92,93]. This illustrates the synergies among various NbS when implemented in conjunction, with their

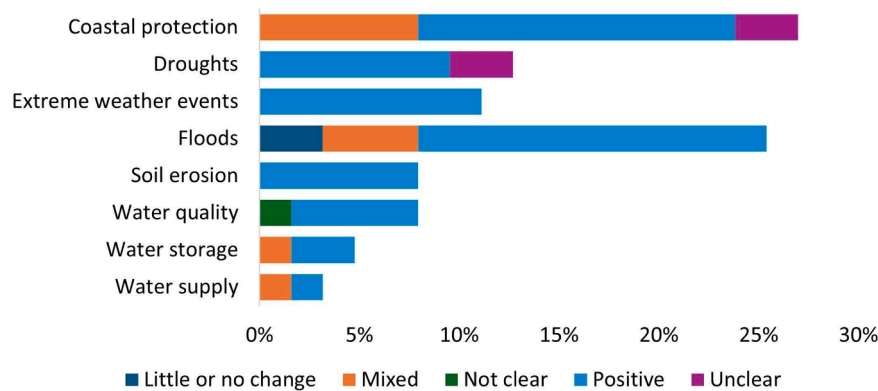


Fig. 8. Outcomes of the NbS intervention in addressing water challenges.

effectiveness being contingent upon scale and locality. If implemented in isolation rather than in synergy, the solutions may prove ineffective.

For coastal protection, several studies reported mixed results, highlighting the pitfalls of bamboo fences as NbS intervention or the low survival rate of non-native mangroves. Although positive outcomes are observed in certain instances, the rapid accumulation of sediments and the short lifespan of bamboo, which leads to decay within 2 to 3 years, result in negative consequences, including harmful bamboo debris affecting the local fishing community during their activities. Their outcomes are influenced by location; for instance, strong winds and higher waves may hinder the success of interventions [68]. Most of the studies are also looking at biophysical aspects of the solutions and they may have overlooked the social and economic aspects of the solution [94]. While the interventions may be successful in terms of biophysical indicators, it is also important to account for social and economic outcomes. In case of drought, the studies mostly measure income improvement which is important to help build resilience of the community during the drought. For example, NbS such as contour plantation, which generates additional income by planting fruit trees such as orange at Son Tho Commune, Vietnam, as part of a pilot EbA [95].

3.3.3. Integration of traditional indigenous knowledge within NbS

Many of the NbS interventions documented in this review are adaptation focused or revivals of long-standing traditional practices—for example, furrow irrigation and living weirs in Thailand, water-wood management systems in China, and the restoration of ancient irrigation lakes in Cambodia. Furrow irrigation has existed for generations but gained renewed national attention when reframed under the “Monkey Cheeks” flood-retention concept promoted by Thailand’s King [96]. They existed for decades, before the concept of NbS. Framing them as NbS can bring the shift in how these practices are conceptualized and legitimized in environmental research and policy, often aligning them with donor priorities and international reporting frameworks. While peer-reviewed literature rarely interrogates this relabeling process, grey literature more frequently acknowledges the role of traditional ecological knowledge in such projects—though these interventions are often funded and led by international agencies with varying level of participation from local institutions [49]. This raises critical questions about epistemic justice: whose knowledge is recognized as authoritative, how traditional practices are reframed to fit global narratives, and whether the benefits—and decision-making power—are equitably shared with the communities who have long maintained these systems [97].

3.3.4. Role of participatory governance, stakeholder engagement and traditional practices in NbS implementation

Governance is a decisive factor in the success and sustainability of NbS, influencing not only how interventions are designed and

implemented, but also who benefits from them. Effective NbS require participatory processes—co-production, shared stewardship, and mechanisms for long-term maintenance [38,98]. Our review indicated that these components fell outside the scope of most peer-reviewed studies, which either did not address the topic or failed to provide detailed elaboration. Two case studies in Thailand and Vietnam focused on stakeholder engagement and noted that intensive community consultation occurred during the process, resulting in positive outcomes, including local communities taking measures to protect the site [68].

In contrast, grey literature often provides richer accounts of governance process, highlighting how traditional ecological knowledge, customary practices and local governance structures enable the success of NbS. Examples include heritage landscapes - forest-village-terrace-water system - conservations, where customary laws empower communities to lead resource management. In some cases, these traditional governance arrangements have been formally recognized and incorporated into statutory frameworks, enhancing legitimacy and compliance [99]. Similarly, indigenous organisations such as Green Watershed in China have collaborated with Water User Associations to implement collective water management, demonstrating how local governance can complement formal institutional structures [100].

However, the governance landscape is uneven. Large-scale government-led programmes, such as lake watershed restoration and coastal and urban green infrastructure in China [49,101], can mobilize substantial resources at watershed scale but often operate through top-down models that limit genuine community decision-making. While some initiatives establish joint working groups to promote “inclusive governance”, few provide detailed accounts of how authority, responsibilities, or benefits are shared among stakeholders. Moreover, many NbS initiatives in Vietnam, Cambodia, Myanmar, and even in Thailand are funded by international donors such as ADB, GEF, IKI, UN agencies, GIZ, the UK, and the Dutch government. These projects are aligned with the Vietnamese-Dutch governments co-produced Mekong Delta Plan (2013) and often involve foreign technical firms and experts in project design and planning. While implementation typically occurs with local government partners, donor-driven priorities and external technical leadership can influence project objectives, governance structures, and the degree of local participation and ownership.

Evidence from our reviewed literature suggests that integrating traditional practices, addressing donor-recipient power dynamics, and strengthening participatory governance not only improve ecological outcomes but also enhance social legitimacy. However, there are institutional barriers to the sustainability of the implementation. For example, in Vietnam coastal area, community-based mangrove management boards (CMMBs) face institutional barriers despite their early successes. A key challenge is that mangroves are legally designated as *Special Use or Protection Forests*, which does not allow communities to secure long-term tenure rights. As a result, CMMBs operate with short-

term contracts and incentives, limited authority, and unstable funding—conditions that does not favor accountability and reduce local incentives for sustainable, long-term stewardship [102].

The ASEAN Study on Nature-based Solutions [13], which emphasizes governance, financing, and equity as enabling factors for scaling NbS implementation, recommending to strengthen policy framework and involving private sector financing. This resonates with our finding that while peer-reviewed studies often focus on biophysical or economic outcomes, grey literature more explicitly documents challenges of participation, rights, and donor dependency. Together, these insights underline that scaling NbS in the GMS requires not only technical evidence but also attention to inclusion and enabling governance conditions.

Future research would benefit from examining these governance dimensions explicitly, particularly how formal and informal systems interact, how funding structures shape priorities, and how power dynamics affect the ability of communities to engage as equal partners in NbS implementation.

3.3.5. Co-benefits

One of the advantages of NbS compared to conventional grey infrastructure is that it provides multiple benefits in addition to addressing targeted environmental challenges [103]. They can provide ecological, social and economic benefits such as emission reduction and creating job opportunities [38], biodiversity gains [104], or improving urban livability while mitigating floods [105]. Table 4 Reported co-benefits of the NbS for water challenges Table 4 presents the reported co-benefits of various NbS interventions, categorized into social, ecological and economic dimensions.

Social benefits of NbS include cultural, recreational, and livelihood opportunities. For example, forest protection were reported to provide nature-based recreation and support livelihoods for forest-dependent communities [106]. Wetlands creation/restoration were found to contribute to recreational opportunities and improve the aesthetic of a city environment [63], thereby enhancing the quality of life.

Ecological co-benefits such as carbon sequestration and improvement of biodiversity were reported in furrows and forest protection. In

economic benefits, the studies reported saving costs on agricultural productivity, increased income, irrigation and water supply. Regarding ecological benefits, climate related and ecosystem health benefits such as carbon mitigation, and biodiversity were reported. Studies related to furrows reported largest numbers of co-benefits because one study [91] has applied an assessment framework with many indicators. However, it does not mean that other NbS do not provide co-benefits, given that some of the studies solely focus on assessing the effectiveness for biophysical aspects of water management, such as the level of flood peaks [93,107].

The range of reported co-benefits varies among interventions and studies, reflecting differences in study scope and assessment methodologies. Comprehensive frameworks, as demonstrated in [90,108,109], enable studies to evaluate a wider array of potential co-benefits. However, scenario modelling becomes more complex and challenging when attempting to render models for larger spatial scales that encompass multiple benefit aspects. The restricted documentation of co-benefits suggests additional research employing a more comprehensive evaluation of various types of NbS to better understand their multifunctional value and associated trade-offs within the context of the Greater Mekong Subregion (GMS).

3.3.6. Economic evaluations of NbS interventions

Assessing the economic viability of NbS allows practitioners to compare costs and benefits of NbS with conventional grey infrastructure solutions. Such an assessment can provide important cues for policy-makers, stakeholders, and funding agencies to make informed decisions regarding the implementation and scaling of NbS. Cost-benefit analyses (CBAs) help assess the cost-effectiveness and trade-offs of NbS, but few studies have focused on this aspect. Our review found only one study conducted CBA for NbS for wastewater treatment, but it did not differentiate the costs and benefits of NbS from other solutions like aerated lagoons [108]. Although not comprehensive CBA, another study on payment for ecosystem services in a protected forest found that, despite higher management costs, the overall benefits—such as flood protection, water supply, and livelihoods—outweighed the costs compared to an unprotected scenario [109].

In a study that analyzed economic benefits of an EbA measure - sediment pool by wetland restoration/creation - to maximize reservoir storage capacity without dredging [65], demonstrated that the economic benefits of the EbA measure in comparison with dredging, increased overtime. Although the study noted other positive impacts such as mitigation of drought and flood, it did not elaborate the assessment further. Similarly, economic benefits of rainwater harvesting in a rural area [89] proved that households can save more money by harvesting rainwater instead of buying bottled water. These systems can be particularly beneficial in areas where water resources are limited, and traditional water infrastructure may be inadequate or expensive to maintain.

Despite these relatively positive findings, the review highlights a considerable gap in the economic evaluations of NbS in the GMS. Only 4 studies focused on economic valuation, which underscores the need for further research in this area. Expanding the scope of economic evaluations to include a broad range of NbS and their co-benefits would provide a more comprehensive understanding of their value and effectiveness.

3.4. Effectiveness criteria

Across the reviewed studies, not all studies meet all four effectiveness criteria—socioeconomic benefits, sustainability, conservation, and multifunctionality. Interventions meeting all criteria were (Fig. 9) often supported by strong local governance arrangements such as community-owned forests being conserved, and landscape – cultural approaches [49,110].

For example, mangrove restoration projects that formed community

Table 4
Reported co-benefits of the NbS for water challenges.

NbS types	Reported co-benefits of NbS	
Furrows	Economic	Irrigation cost
		Agricultural productivity
	Ecological	Improved incomes of farmers
		Connectivity
		Infiltration
		Biodiversity
		Soil quality
		Fertilizer reduction
		Air quality
	Social	Cultural and spiritual
		Education and research
Wetlands creation/restoration	Economic	Dredging cost
	Social	Recreation
		Social acceptability
		Aesthetic appearance
	Ecological	Ecosystem health
Forest protection	Social	Carbon sink
		Livelihoods/good supply
		Nature-based recreation
	Ecological	GHG sequestrations
		Carbon stock
Mangrove protection/restoration	Economic	Water supply cost
	Ecological	Climate regulation
	Social	Livelihoods/good supply
		Recreation
UGI	Social	Thermal comfort
EbA measures	Social	Livelihood opportunities
		Cultural conservation
Water harvesting	Economic	Reduced cost of drinking water

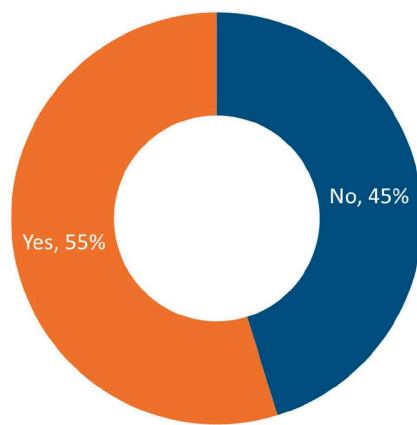


Fig. 9. Proportion of studies meeting all four effectiveness criteria.

management body tended to deliver both ecological and livelihood benefits over the long term. The coastal forest restoration project in central Vietnam [49] shows how effectiveness depends on governance rather than intervention type alone. By restoring dunes and mangroves with native species through a co-management approach, the project secured community ownership even beyond the project timeline, livelihood co-benefits, and maintenance. Even under extreme storm events, adaptive monitoring and local engagement enabled recovery and continued ecological and socio-economic gains. In contrast, interventions achieving only partial effectiveness often faced constraints such as no community buy in, or limited stakeholder engagement. These results suggest that effectiveness is not solely a function of the intervention type but is result of enabling governance contexts, alignment with local needs, and the capacity for long-term maintenance. Future interventions should thus prioritize institutional and financial mechanisms that can sustain benefits across all four criteria, while recognizing that trade-offs may require negotiated compromises in certain contexts. One notable point is that majority of those are grey literature as their scope expands beyond technical and biophysical measures. Peer-reviewed literature, in most cases, was limited by their study scope and did not discuss and elaborate such context and governance criteria. This finding emphasizes the necessity for a comprehensive assessment framework and a holistic methodology in the design and evaluation of NbS interventions to ensure their adoption, long-term sustainability, and effectiveness.

Box

4. Conclusion

This review reveals a clear imbalance in the literature on NbS for water challenges in the Greater Mekong Subregion, with significant gaps in Cambodia, Lao PDR, and Myanmar despite existing policy commitments [111]. This finding resonates with the findings of earlier studies [4,112]. Similar to the other regions in the Global South like sub-Saharan Africa [5,113], the Mekong Region has limited scholarly

documentation on the effectiveness and monitoring of large-scale impacts of NbS. While the existing literature has shown the positive outcomes of NbS to address water challenges in the Mekong Region, more efforts are needed to quantify their economic benefits, assess governance aspects, power dynamics and strengthen the evidence on their effectiveness. Integrating traditional knowledge and practices within NbS is equally vital. They can offer context-specific insights and culturally appropriate approaches that can enhance the design, legitimacy, and long-term sustainability of NbS. Recognizing and embedding these knowledge and practices alongside scientific evidence will be critical for more inclusive approach. Although many frameworks have been developed to assess the effectiveness of various NbS for water issues [114], few of them have been actually applied [91]. Another major challenge to scale up NbS implementation is that NbS are highly context-specific, the application of existing evaluation frameworks necessitates its contextualization to align with NbS interventions. Peer-reviewed literature tends to emphasize technical or biophysical aspects, whereas grey literature more frequently discusses governance.

Our findings point to several important directions for future research in the GMS region. First, there is a need to examine how governance structures and socio-political contexts in Cambodia, Lao PDR and Myanmar influence the implementation and uptake of NbS. Further studies are also required to identify which NbS approaches are most effective in enhancing water quality, supply and drought resilience within Mekong. Moreover, developing robust methodologies to capture the economic and social co-benefits of NbS alongside ecological outcomes remains a critical gap. The limited application of existing NbS evaluation frameworks raises concern regarding their suitability and need for adaptation to local contexts and existing institutional capacities. Finally, the role of transboundary water politics, national priorities and influence of regional frameworks such as ASEAN and MRC remains underexplored, yet these factors are likely to be pivotal in shaping future trajectory and effectiveness of NBS in the region. Scaling up NbS will also require more enabling policy environments. Our review suggests several priorities: (i) empowering local authorities and communities through participatory planning and long-term stewardship mechanisms; (ii) co-developing transparent reporting and monitoring standards with donors and NGOs to reduce bias and improve learning; (iii) strengthening cross-border collaboration and knowledge exchange through the Mekong River Commission, ASEAN climate initiatives, and NDC frameworks; and (iv) securing sustainable financing from both national governments and regional institutions, rather than relying primarily on external donor projects.

Overall, scaling NbS in the GMS depends on bridging science, policy, and practice—aligning local realities within broader national, regional and global frameworks—to ensure solutions are effective, equitable, and resilient in the face of rapid environmental and geopolitical change.

NBS impacts and implications

Environmental: The submitted manuscript demonstrates how effective nature-based solutions have been in addressing water challenges such as floods, droughts, coastal erosion and sea level rise in the Greater

Box

Future research agenda for Advancing NbS in the GMS.

Emerging gaps identified in this study point to several underexplored areas that should receive further scholarly and policy attention:

Effectiveness monitoring beyond biophysical metrics – Develop multi-dimensional monitoring frameworks that incorporate social acceptability, and livelihood co-benefits.

Financing and long-term maintenance – Examine sustainable financing mechanisms, including blended finance and community-based models, to ensure continuity beyond externally funded project cycles.

Equity and justice – Investigate who benefits and who bears the costs of NbS interventions, especially where access, land rights, or labor contributions are unevenly distributed.

Local knowledge integration – Explore how customary practices, indigenous knowledge and everyday water management strategies can inform context-sensitive NbS design and monitoring frameworks.

Governance and institutional capacity – Assess the governance structure, coordination mechanisms, and policy that enable or constrain long-term implementation and scaling-up.

Recognition of small-scale and informal NbS practices – Document and analyze locally embedded, small-scale interventions that remain outside formal project reporting but may offer scalable adaptive models.

Mekong Subregion (GMS).

Economic: It also highlights which types of NBS have been cost-effective in comparison to traditional grey infrastructure when addressing water challenges in the GMS.

CRedit authorship contribution statement

Khaing Su Lwin: Writing – original draft, Visualization, Validation, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Ridhi Saluja:** Writing – original draft, Writing – review & editing, Visualization, Validation, Supervision, Software, Methodology, Investigation, Data curation, Conceptualization. **Sushmita Mandal:** Writing – review & editing, Supervision. **Chayanis Krittasudthacheewa:** Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

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

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Supplementary materials

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Data availability

Data will be made available on request.

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