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Research progress and application prospect of nature-based solutions in China

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In recent years, Nature-based Solutions (NbS) have become an important concept in the field of climate change and sustainable development. The study screens academic journals relevant NbS researches using China National Knowledge Infrastructure (CNKI) and Web of Science database to explore different perspectives for Nature-based Solutions research through qualitative analysis. This study reviews the existing research on NbS, summarizes what research ideas are covered by Nature-based Solutions, as well as the relationship between previous relevant studies, focuses on different perspectives of refining the implementation of Nature-based Solutions in various studies and practices, and explains them with typical cases. The research shows that existing Nature-based Solutions researches mostly prefer to determine schemes by objects, with insufficient emphasis on subjects and goals. On this basis, the specific operational framework of promoting Nature-based Solutions in China is considered to promote the development of indigenous application of Nature-based Solutions in China. This study reveals the diversified ideas in the research and implementation of Nature-based Solutions at home and abroad, which is of practical significance to promote the localization of Nature-based Solutions in China.

KEYWORDS

nature-based solutions (nbs), research progress, ecological restoration, localization of NbS, application prospect

1 Introduction

Cities are facing challenges of sustainable development, such as climate change, biodiversity loss, flood, drought, extreme high temperature. The sustainable development of urban and rural areas has become a recognized global wicked problem (Xiang, 2013). In order to solve a series of challenges faced by urban and rural areas, such as resource consumption, environmental pollution and ecosystem degradation, more and more scholars call for natural and ecosystem based methods to transform urban and rural areas to increase ecosystem resilience (Scott and Lennon, 2016; Lafortezza et al., 2017). China's urban and rural areas have different development levels and characteristics, so its sustainable development also faces a series of challenges. Although there is no clear solution, respecting nature has become a consensus concept in land use and ecological restoration (Wang and Yuan, 2019). At the same time, scholars' research also focuses on how to implement these "natural concepts" (Wang et al., 2020a). Nature-based solutions (NbS) provide a collaborative governance idea for addressing such challenges.

The World Bank first presented NbS in its 2008 report named *Biodiversity, Climate Change and Adaptation: Nature-Based Solutions in World Bank Investments*, and described it as "a more systematic understanding of the relationship between people and nature", pointed out that NbS should protect biodiversity and improve sustainable livelihoods while mitigating and adapting to the impacts of climate change (The Word Bank, 2008). The International Union for Conservation of Nature (IUCN) has defined NbS as: actions that effectively and adaptively address social challenges and provide benefits to human wellbeing and biodiversity through the conservation, sustainable management and restoration of natural or man-made ecosystems. It also suggested tackling climate change by NbS (IUCN, 2016). Over the past decade, it has blended this concept into about 100 investment projects, such as the support of Colombo wetland in Sri Lanka for urban flood control, and mangrove restoration in Vietnam. NbS includes a series of umbrella concepts based on ecosystem approach, such as natural climate solutions (NCS), ecosystem based adaptation (EbA), ecosystem based disaster risk reduction (Eco DRR), green infrastructure (GI), it plays an important role in addressing a number of major social challenges, including climate change mitigation and adaptation, disaster prevention and reduction, economic and social development, human health, food security, water security, ecological environment degradation and biodiversity loss (IUCN, 2020).

NbS is the development and integration of previous concepts (Lin and Sun, 2020), such as green infrastructure, natural capital (Sarukhan et al., 2005), ecological design and design ecology (Wang, 2017), ecosystem approach and other related concepts (Campbell et al., 2008), and has similar connotation with the recent concept of "natural idea" in China. The recent research on NbS is mainly concentrated in developed countries in European and American area, and has accumulated some experience and lessons, such as the NbS Roadmap for America, the EU Biodiversity Strategy for 2030, and The Post-2020 Global Biodiversity Framework. From ancient times some of planning and design, practice of ecological protection and restoration in China are also closely related to NbS. In order to effectively learn from the related experience at home and abroad, the study reviewed the existing research and analyzed the research progress of NbS. On this basis, it looks forward to promoting the specific application and operation framework of NbS in China and promoting the localization development of NbS in China.

2 Data sources and research methods

2.1 Data sources

The main subject of this article is the NbS. The literature studies that the author has studied are papers in the web of science and CNKI database. The survey was conducted in October 2022, mainly searching the papers of the last 10 years. The "search terms" procedure was designed according to the application field of NbS, by reading the title, abstract and conclusion of the paper, search terms irrelevant to NbS were eliminated. The results of literature retrieval influenced our decision to use these terms. The author set the search terms as NbS, ecological conservation and restoration, ecosystem, climate change, biodiversity, natural financing. The index results showed that 324 articles studied the NbS from journals in the web of science database, 183 papers related to the theme of NbS in the CNKI database. The author removed the articles from the first online journals and other volumes that were not part of the research papers. Eventually, 126 relevant literature studies including reviews and articles were pitched to analyze and study.

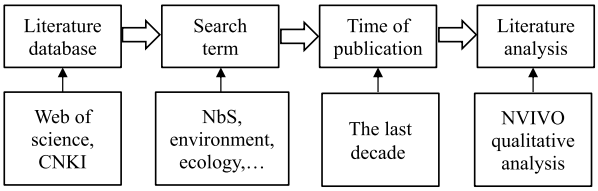

FIGURE 1
A flow chart of Nvivo-Qualitative Data Analysis in NbS.

2.2 Research methodology

The study mainly uses qualitative research methods to summarize various research perspectives on NbS at home and abroad. First, the preliminary reading of the text data, in order to grasp the overall framework and main content; Then Nvivo12 software is used to encode the initial text data to get the corresponding child nodes; Finally, the parent node is further refined from the child node, which is the research perspective of NbS (Figure 1). With the perspective of NbS as the focus for the study, the perspective and keywords of the collected literature was labeled by NVIVO qualitative analysis software (Pan and Tang, 2020); Extracting the whole paragraph content related to the core research perspective for subsequent text analysis materials, using the method of text analysis, the pattern rules between topics or features in the literature were summarized and analyzed. The keywords of each article are classified into unsupervised classification (algorithm direct classification) and supervised classification (manual classification). The words with similar connotation are classified into one category based on the two classification results, summarize the patterning rules between the themes or features hidden in the literature, so as to systematically refine various research perspectives of NbS. Finally, it explains the research perspective and significance of the literature to form a clear research viewpoint.

3 Research hotspots and evolution trends

3.1 Research hotspots

The key words or subject terms in the literature can reflect the core content and research hotpots of the study. The authors

TABLE 1 Top ten high-frequency emergent words.

Number	Keywords	Frequency
1	Climate change	37
2	Ecosystem services	31
3	Green infrastructure	28
4	Sustainable development	23
5	Climate resilience	19
6	Biodiversity	16
7	Urban green space	14
8	Ecological restoration	11
9	Landscape management	9
10	Stakeholder engagement	7

analyzed the high-frequency keyword co-occurrence and summarized the hot spots of the research of NbS in each literature. These keywords include climate change adaptation, ecosystem services, green infrastructure, sustainable development, climate resilience, urban green space, climate-change adaptation and mitigation, landscape management, stakeholder engagement (Table 1). In summary, they focus on ecological conservation and restoration, urban waterlogging mitigation, climate change response, biodiversity conservation, challenges of sustainable development, urban water management, economic transformation and ecosystem carbon sink, reflecting the research hotspots of NbS in the recent years.

3.2 Evolution trends

In the 1990s, the term "NbS" was first proposed in the field of biodiversity, and then was cited in agricultural development, land use planning and industrial design (Wang and Hou, 2021). Now it is widely used in climate change, urbanization, food security, water supply, and disaster risk. (Chen and Lin, 2019). In the field of environmental and natural protection, NbS is a "sustainable and cost-effective solution to social challenges such as global warming, water management and human health and promote the development and management of urban ecosystems, while enhancing biodiversity" (Eggermont et al., 2015). The NbS covers a range of ecosystem related measures. IUCN puts forward a classification system of measures according to the purpose, effectiveness and orientation (Cohen-shacham et al., 2016), NbS approaches including policies, management systems, plans, measures, projects, formulated for an ecosystem or specific problems (Table 2).

Internationally, IUCN, the World Bank, the European Union, UNESCO and other institutions have formed project support for special research related to NbS, especially in water resource management, flood control and other aspects. In 2012, the World Bank prepared a research report on the application of NbS to water resources protection in East Asia, and supported 60 countries to implement about 100 projects related to NbS; In 2015, the European Commission included NbS in the "Horizon 2020" research plan (Church, 2015); In 2018, UNESCO, together with other relevant international institutions, released the United Nations World Water Development Report on the theme of "nature based solutions for water" at the 8th World Water Forum; IUCN released the global standard of NbS, trying to unify a series of different methods from different fields into one operational framework, expand its implementation scope, and improve its influence in relieving the pressure of challenges that the world needs to solve urgently (IUCN, 2019).

3.3 Main research content

Based on the analysis of the occurrence time and frequency of keywords, the main research contents of NbS were divided into four aspects (Table 3).

1) Implementation objects of NbS

The research on the implementation objects of NbS is mainly in three aspects. First, in terms of infrastructure, it emphasizes the connectivity of green infrastructure and corridors from the perspective of landscape elements, such as the green belt around London in the United Kingdom (Davies et al., 2015) and the gray infrastructure greening in Philadelphia in the United States (Wang and Lin, 2015); The second is to implement nature based ecological restoration solutions for different ecosystems. For example, China has launched a pilot ecological restoration project of "mountains, rivers, forests, farmlands, lakes, grasslands and sandy lands" to repair areas with severely damaged ecosystems, and promote ecological protection and restoration. In addition, river ecosystems (Boelee et al., 2017), forest ecosystems (Ordóñez, 2019), urban

TABLE 2 Categories and examples of NbS approaches.

Categories of NbS approaches	Examples
Ecosystem restoration methods	Ecological restoration; Ecological engineering; Forest landscape restoration
Ecosystem related approaches to specific problems	Ecosystem-based adaptation; Ecosystem-based mitigation; Climate adaptation services; Ecosystem-based disaster risk reduction
Infrastructure related approaches	Natural infrastructure; Green infrastructure
Ecosystem based management approach	Integrated coastal zone management; Integrated water resources management
Measures for ecosystem protection	Area-based approaches to conservation, including reserve management

TABLE 3 The main research contents of NbS.

Aspects	Related content
Objects	Green infrastructure, ecosystem, Social challenges
Subject	The relation between human and nature, Ecological restoration type
Goals	Ecosystem services, Sustainable development objectives
Approach	Landscape Design, Ecological restoration, Climate change, water resources crisis

and cultural ecosystems (Engstrom et al., 2018; Frantzeskaki et al., 2020) were taken as the research objects to study corresponding methods of ecological protection and restoration; Third, apply NbS to address social challenges, mainly including water security, climate change, public health and welfare, or to address natural disasters, ecological recovery and other challenges and problems faced by urban development. The social challenges facing cities include climate change, biodiversity, water security, food security, economic and social development. Some of these social challenges are universal and some are local. Taking climate change as an example, some scholars believe that various schemes for mitigating climate change depend on the synergy of each ecosystem, such as forests, grasslands, farmland, wetlands, oceans, and cities (Zhang et al., 2020). It requires comprehensive application of ecology, geography, management and other disciplines to achieve complementary effects (Klink et al., 2016; Siegner, 2018).

2) Implementation subject of NbS

In terms of the research on the implementation subject of NbS, the role of human and nature in NbS was mainly discussed. According to the relationship between nature and human, types of ecological protection and restoration approaches were divided (Swart et al., 2001), and views on the balance between ecosystem and human activities were put forward (Yaffee, 1999). Another perspective of the implementation subject research is to explore the role of stakeholders and decision-makers in the implementation of NbS, such as the definition of the responsibilities of the government and enterprises in ecological restoration, and the obligation of enterprises to carry out ecological restoration if the ecosystem is damaged in the process of resource development and utilization (Li and Liu, 2022); When the responsible party for ecological restoration is unclear, the government takes the lead in carrying out restoration projects for the damaged ecological environment. The ecosystems of NbS can be divided into forest, grassland, farmland, wetland, ocean and city. The traditional environmental policy instruments were applied to group the policy instruments of NbS in command-and-control regulations, incentive policies, and voluntary participation (An et al., 2021). NbS plays an important role in coping with climate change as well as conserving biodiversity, and it also has great potential in the co-governance. China has made sort of achievements in the co-governance of cope with climate change and biodiversity conservation. The idea of NbS is embodied in policies such as the ecological protection red line system, which was also considered as the bottom line of national and regional ecological security, delineated a strict management-control boundary for areas such as important ecological functional areas, eco-environmental sensitive areas and fragile areas. The administrative mechanism of nature reserve network dominated by national park, the establishment of priority areas for biodiversity conservation and the implementation of major ecological conservation and restoration projects (Zhang and Yin, 2022).

3) Implementation goals of NbS

The implementation goals of NbS mainly focus on two aspects: ecological protection and restoration and ecosystem services. For example, river ecological restoration considers each element as a life community and determines the ecological restoration goals of river courses. The expected function of ecosystem services is the ultimate goal of many NbS studies abroad, which emphasize how to build a bridge between NbS and ecosystem services, so as to realize the trade-offs and synergies of ecosystem services in different spaces and practical scales (Almenar et al., 2021; Calliari et al., 2019). In addition, the concept of nature's contribution to people (NCP) is similar to ecosystem services. The NCP was divided into three categories: intrinsic value, instrumental value and relational value (Pascual et al., 2017). How to realize the sustainable development of ecosystem through NbS is also a major focus of recent research (Wendling et al., 2018). NbS can cope with the closely related challenges such as ecosystem degradation, biodiversity reduction, human welfare and climate change (Cassin et al., 2021). Access to safe water is the most basic human need for health and wellbeing. Demand for water is rising owing to rapid population growth, urbanization and increasing water needs from agriculture, industry, and energy sectors. While realizing water security, NbS can help achieve multiple other SDGs sub-goals, such as "poverty eradication" (SDGs-1, the role of water on livelihoods), "zero hunger" (SDGs-2, and NbS provides sustainable water for agriculture) and other goals (SDGs-3, Good Health and Wellbeing; SDGs-6, Clean Water and Sanitation; SDGs-11, Sustainable Cities and Communities; SDGs-13, Climate Action) (Bremer et al., 2021). Sustainable city construction advocates the return of urban areas to nature and provides habitats for plants and animals, the urban heat island effect can be improved by planting trees, and the construction of roof gardens, campus green space and large urban parks can reduce the energy required for the environment. (Raffaele and Giovanni, 2019). In addition, NbS provides natural guarantee and mitigation measures for extreme natural

disasters, among which the most typical case is the construction of natural catchment to avoid flooding of farmland (Marianne et al., 2021), and the catchment can also solve the problem of water shortage in extremely arid climate (Areeja et al., 2022).

4) Implementation approach of NbS

Aiming at specific ecosystem or social challenges, the NbS program focuses on the degree of damage to the ecosystem, and proposes different ideas for ecological protection and restoration, such as repairing the ecological disaster area, restoring the ecosystem with damaged functions, improving protected natural areas and elevating semi-natural landscapes (Hobbs and Norton, 1996). Some scholars put forward concepts related to ecological protection and restoration of different degrees: ecological restoration, ecological rehabilitation, ecological reconstruction, ecological replacement (Chen, 2019). The Sustainable Sites Initiative (SITES) in the United States creates sustainable and resilient land development projects directly based on site characteristics. The initiative is generally divided into four categories of development and design: conserve, manage, restore, and regenerate (Danielle et al., 2017). NbS schemes for single social challenges are also research hotspots, such as water-related challenges (Boelee et al., 2017), biodiversity conservation and food security crises (Wang et al., 2020b). NbS is regarded as an important part of climate change mitigation and adaptation strategy (IUCN, 2016). The Nature Conservancy (TNC) has put forward a set of Natural Climate Solutions (NCS), the forests, wetlands, agriculture and grasslands are the most important paths which have attracted much attention (Griscom et al., 2017). Many domestic and foreign researchers have conducted detailed research and exploration on climate change (Chausson et al., 2020; Seddon et al., 2021), and further proposed various natural solutions to climate change (Tian et al., 2021).

4 Research conclusions and application prospect

4.1 Conclusion of the study

The study tries to estimate the research progress of NbS by analyzing the research hotspot, research content, and the evolution trend of research direction using literature analysis software. The result shows that the research frequency of NbS is on the rise, and the number of articles has gradually increased in recent years, and the high-frequency co-occurring words with NbS mainly involve climate change, biodiversity, ecological conservation and restoration, resilient city, urban sustainability and sustainable development, reflecting the research hotspot in different fields. In addition, the main content includes the localization of NbS, carbon neutrality, economic transformation, sponge city, and water management. Last, from the perspective of the evolution trend of research content, the research content gradually changes from theoretical research to engineering practice and policy formulation of NbS. This study lacks a comprehensive understanding of the NbS theory, and fails to put forward effective countermeasures for the obstacles faced by the practice of NbS localization. It is necessary to research localized results based on the characteristics of different regions and the problems to be solved in China.

4.2 Application prospect

As NbS is increasingly proving to be a hot topic in the field of natural resource management and ecological conservation, its concepts and technical approaches are increasingly being discussed and practiced. Based on the analysis of the current predicament and research progress of NbS, the authors assume that more attention should be paid to the following area:

1) Promoting the co-governance of cope with climate change and biodiversity conservation. NbS plays an important role in coping with climate change as well as conserving biodiversity, and it also has great potential in the co-governance. The NbS can effectively mitigate and adapt to climate change, improve climate resilience, and bring benefits to human welfare and biodiversity conservation by protecting, repairing and sustainably managing ecosystems, improving ecosystem service functions, and increasing carbon sinks. It has become an important link and bridge to address climate change and biodiversity conservation synergies. It is recommended to mainstream NbS in responding to climate change, from three aspects-theoretical and scientific research, policy formulation, and supervision-to to promote capacity-building and the willingness to participate.
2) Enhance ecosystem carbon sink, reduce carbon emissions. “Carbon peak in 2030 and carbon neutralization in 2060” has been established as one of the important strategic goals of China’s economic and social development. To enhance the carbon sink capacity of Chinese terrestrial ecosystems, it is necessary to implement some important ecological protection and ecological restoration projects at large scale. To maximize NbS in China, NbS should be included in nationally determined contributions and quantitative goals should be proposed at the next stage. China will scale up its intended nationally determined contributions by adopting more vigorous polices and measures. China aim to have carbon dioxide emissions peak before 2030 and achieve carbon neutrality before 2060.
3) Strengthen city resilience and advance urban sustainability. Under the context of global warming and rapid urbanization, cities worldwide are increasingly facing problems of environmental pollution and ecosystem degradation, one of the grand challenges in achieving Sustainable Development Goals. Such challenges call for new frameworks and approaches for improved urban ecosystem management. NbS has now been increasingly recognized as an effective means to mitigate ecological risks, strengthen city resilience and advance urban sustainability. The potentials of applying NbS on climate adaptation to enhance urban resilience, like stormwater management *via* restoration of natural water body, utilization of rainwater and optimization of urban landscape. NbS plays an important role not only in flood control, but also in biodiversity conservation. Building urban resilience through “green recovery” will certainly promote global sustainable development.

4) Localization of NbS in ecological conservation and restoration. The transformation and absorption of NbS by the Ministry of Natural Resources has made NbS mainstream in China's ecological protection and restoration work. However, NbS is still immature in the world, and the research mainly focuses on the natural disaster prevention and the urban level, most of which ignores the ecological space as an important component. To incorporate NbS into the national policy system and bring the idea into the vital ecological space supervision and evaluation index system. China should incorporate biodiversity conservation into its climate policy system, focus on incorporating NbS into national development strategies such as urbanization and rural revitalization.

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

Author contributions

XH was in charge of designing the experiments and writing the manuscript. XH, HW, and SL were in charge of revising the manuscript. HW was in charge of project administration.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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