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REVIEW

Nature-Based Solutions for Climate Adaptation: A Documentary Review of Progress and Challenges

Soluciones Basadas en la Naturaleza para la Adaptación Climática: Una Revisión Documental de Avances y Desafíos

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ABSTRACT

Nature-Based Solutions have positioned themselves as fundamental approaches to address contemporary climate challenges, by articulating ecological processes with land management. This documentary review examines the progress and limitations in the application of these solutions for climate adaptation, analyzing scientific literature in Spanish and English indexed in Scopus during the period 2020-2025. Through a qualitative methodology, four central thematic axes were identified: the capacity of natural systems for water and thermal regulation, institutional and regulatory frameworks for their implementation, processes of social participation and environmental equity, and challenges for their expansion and financial sustainability. The results reveal that initiatives such as wetland restoration, urban ecological corridors, and vegetative coverings show significant potential for mitigating climate risks, although they face obstacles such as lack of coordination among stakeholders and limited integration into public policies. International experiences demonstrate that the success of these solutions depends on their adaptation to local contexts and on the articulation between scientific knowledge and community wisdom. The study concludes that Nature-Based Solutions require holistic approaches that surpass fragmented views, by integrating ecological, social, and political dimensions to achieve effective transformations in the face of climate change.

Keywords: Nature-Based Solutions; Climate Adaptation; Green Infrastructure; Environmental Governance; Urban Resilience.

RESUMEN

Las Soluciones Basadas en la Naturaleza se han posicionado como enfoques fundamentales para abordar los retos climáticos contemporáneos, al articular procesos ecológicos con la gestión territorial. Esta revisión documental examina los progresos y limitaciones en la aplicación de estas soluciones para la adaptación climática, se analizó literatura científica en español e inglés indexada en Scopus durante el periodo 2020-2025. A través de una metodología cualitativa, se identificaron cuatro ejes temáticos centrales: la capacidad de regulación hídrica y térmica de los sistemas naturales, los marcos institucionales y normativos para su implementación, los procesos de participación social y equidad ambiental, y los desafíos para su ampliación y sostenibilidad financiera. Los resultados revelan que iniciativas como la restauración de humedales, los corredores ecológicos urbanos y las cubiertas vegetales muestran potencial significativo para mitigar riesgos climáticos, aunque enfrentan obstáculos como la falta de coordinación entre actores y la escasa integración en políticas públicas. Experiencias internacionales demuestran que el éxito de estas soluciones depende de su adaptación a contextos locales y de la articulación entre conocimiento científico y saberes comunitarios.

El estudio concluye que las Soluciones Basadas en la Naturaleza requieren aproximaciones holísticas que superen visiones fragmentadas, al integrar dimensiones ecológicas, sociales y políticas para lograr transformaciones efectivas frente al cambio climático.

Palabras clave: Soluciones Basadas en la Naturaleza; Adaptación Climática; Infraestructura Verde; Gobernanza Ambiental; Resiliencia Urbana.

INTRODUCTION

The climate crisis has called for rethinking adaptation strategies from innovative approaches integrating natural systems as key allies. Nature-based solutions emerge as a key paradigm in this context, proposing to use ecological processes to address climate challenges while generating co-benefits for biodiversity and human communities.[1,2,3] This approach represents a shift in perspective from traditional gray engineering solutions, recognizing that healthy ecosystems provide indispensable services for climate resilience. From wetlands that regulate floods to urban forests that mitigate heat islands, nature offers multiple solutions that we are just beginning to understand in their full dimension.[4,5]

The concept of nature-based solutions has evolved significantly in the last decade from a technical notion to a comprehensive framework for climate action.[6,7] Wolf et al.[8] define them as actions to protect, sustainably manage, and restore natural or modified ecosystems that effectively and adaptively address societal challenges. This definition emphasizes three fundamental pillars: ecological conservation, climate adaptation, and human well-being. However, the practical implementation of these solutions faces complexities that require in-depth analysis, particularly in urban contexts where pressures on the territory are more intense.[9,10]

Nature-based solutions have gained recognition in policy agendas and regulatory frameworks, as evidenced by their inclusion in IPCC reports and in the Nationally Determined Contributions of many countries.[11,12] This growing academic and policy interest is supported by evidence of their potential to address multiple challenges simultaneously, from water security to public health.[13] However, significant gaps persist between theoretical knowledge about these approaches and their practical application at relevant scales, especially in regions of the Global South where climate impacts are more severe.[14,15]

Implementing nature-based solutions faces particular challenges in governance, financing, and social participation. Vicarelli[16] and Onofri et al.[17] point out that many projects fail not because of technical limitations, but because of a lack of adequate institutional mechanisms or conflicts with traditional land uses. Furthermore, there is a growing debate on ensuring that these solutions do not reproduce social inequities but contribute to environmental justice processes.[18,19] These complexities require systematic analyses identifying common patterns and lessons learned in diverse geographic and cultural contexts.

In this scenario, it is urgent to consolidate the knowledge generated in recent years on nature-based solutions for climate adaptation by identifying both its advances and persistent obstacles. This article acquires relevance by offering a critical documentary synthesis of the 2020-2025 period, key years for consolidating these approaches in the global climate agenda. This review aims to systematically analyze recent literature on Nature-Based Solutions for climate adaptation by identifying conceptual trends, relevant experiences, and critical challenges in their implementation, to provide inputs for public policies and future research in the field.

METHOD

The present study is based on a systematic documentary review of the scientific literature on Nature-Based Solutions for climate adaptation. This approach allows identifying, analyzing, and synthesizing theoretical and practical advances reported in recent research, offering a comprehensive view of the state of knowledge.[20,21] The review followed rigorous stages of search, selection, and critical analysis of sources to ensure the representativeness and quality of the information collected (figure 1).

This methodological process allowed for a holistic literature analysis by integrating nature-based solutions' ecological, social, and political dimensions. The systematic approach ensured the identification of key conceptual and practical patterns by avoiding bias in selecting sources. By adopting this approach, the review provides a robust basis for understanding nature-based solutions' potential and limitations in climate change contexts.[22,23]

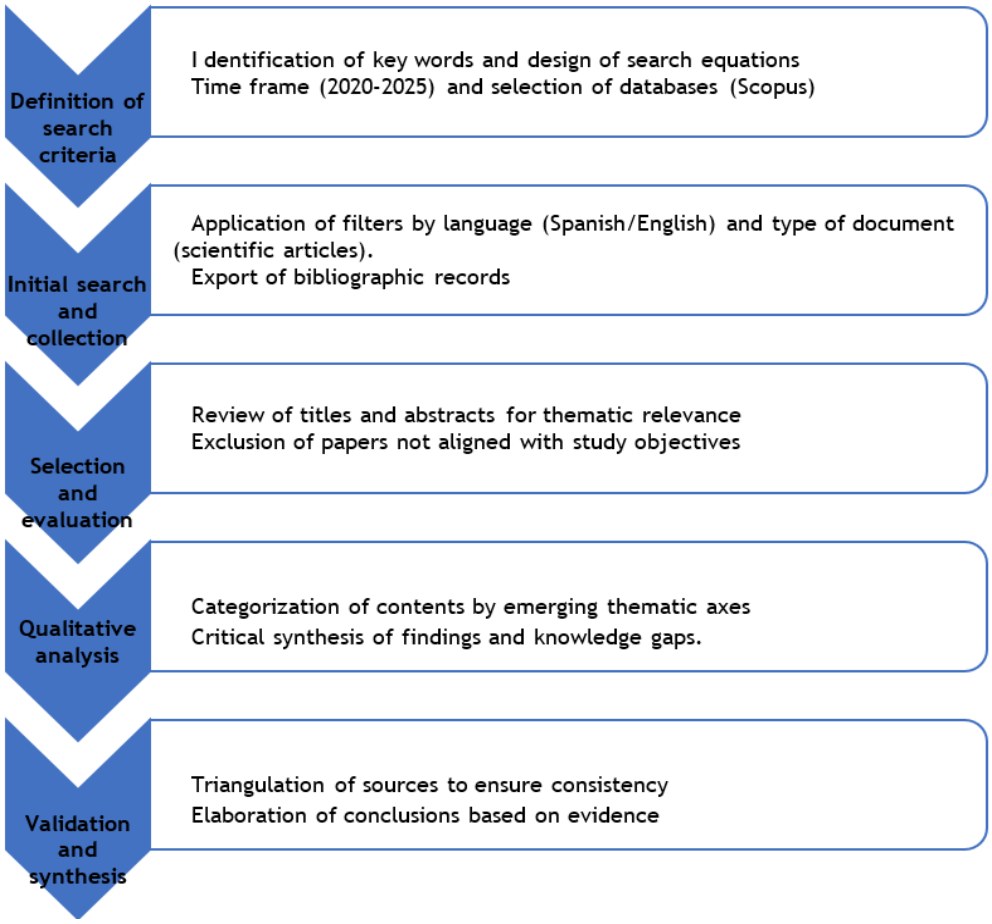

Figure 1. Stages of the document review process

RESULTS

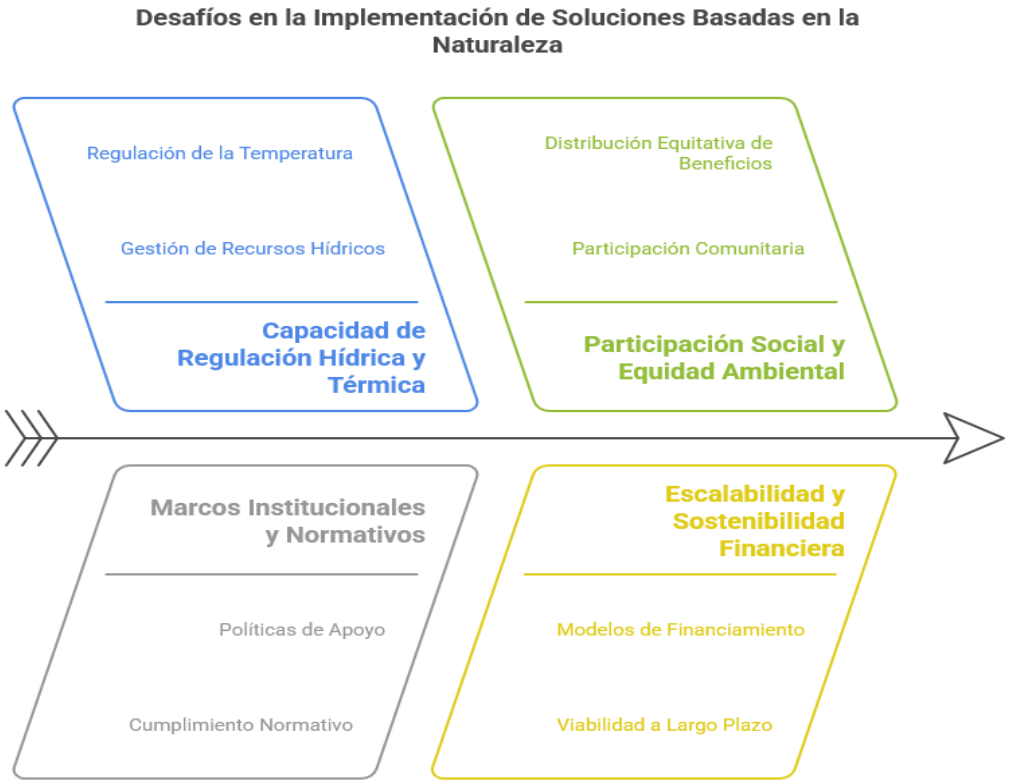

Figure 2. Challenges in implementing nature-based solutions

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The literature review revealed that nature-based solutions for climate adaptation constitute a dynamic and multidimensional field of research, where scientific knowledge, community practices, and public policies converge. The literature reviewed shows that these approaches have evolved from ad hoc interventions to comprehensive strategies that reconcile human development with ecological limits. Through the systematic study of the sources, four fundamental thematic axes emerged that structure the current debate: water and thermal regulation capacity, institutional and regulatory frameworks, social participation and environmental equity, and scalability and financial sustainability (figure 2). These axes do not operate in isolation, but are intertwined in complex dynamics that determine the success or failure of ecosystem-based interventions.

Water and Thermal Regulation Capacity

The studies analyzed highlight the fundamental role of natural systems as climate regulators in urban and rural environments.[24,25,26] Wetlands, riparian forests, and urban green areas function as ecological infrastructures that mitigate extreme phenomena through natural retention, infiltration, and evapotranspiration processes.[27,28] Research in various latitudes demonstrates how these ecosystems can buffer the impacts of heavy rainfall and reduce temperatures in urban corridors by creating more stable microclimates.[29,30]

Wanghe[31] reveals that the effectiveness of these solutions depends critically on their ecological design and spatial connectivity. Well-planned green corridors, for example, not only cool the air but also allow the flow of pollinator species, thus combining climate adaptation with biodiversity conservation.[25,28] However, essential limitations are identified if these systems are implemented in a fragmented manner or without considering the hydrological characteristics of the territory.[32]

A relevant finding is the growing interest in hybrid solutions that combine green infrastructure with sustainable technologies. When integrated with rainwater harvesting systems, green roofs and walls show promising results for the integrated management of the water cycle in dense urban areas.[33,34] However, their long-term effectiveness requires specialized maintenance and adaptation to local climatic conditions.[35]

Salviano[36] also highlights the importance of considering ecological temporalities in the design of these solutions. While some interventions offer immediate benefits (such as rain gardens), others require years to reach full regulatory capacity (such as urban forests). This temporal dimension is often underestimated in conventional urban planning.[31,35]

Finally, studies warn of maladaptation risks if nature-based solutions are not based on rigorous ecological knowledge. Inappropriate selection of plant species or alteration of natural hydrological regimes may generate greater problems than those intended to solve, particularly in contexts of high climatic vulnerability.[26,37]

Institutional and Regulatory Frameworks

Documentary analysis shows that the success of nature-based solutions depends to a large extent on the existence of clear and coordinated regulatory frameworks between different levels of government.[38,39] European cities are leading this process, with specific regulations that require minimum percentages of green infrastructure in new urban developments.[40] The main regulatory advances that have been made in this area are the following.

It is observed that the main regulatory advances occur if nature-based solutions are integrated into existing sectoral policies, such as risk management, land-use planning, and air quality plans.[13,41] However, significant challenges persist in inter-institutional coordination, where competencies frequently overlap or regulatory gaps exist between environmental, urban planning, and water management entities.[42]

A worrisome finding is the frequent disconnection between approved norms and their practical implementation. Factors such as staff turnover, lack of local technical capacity, and pressure from real estate interests limit the materialization of normative advances in concrete interventions in the territory.[43,44]

The analysis suggests that the most successful regulatory frameworks adopt flexible and adaptive approaches, allowing adjustments according to accumulated learning and observed climate changes.[45] In the authors' opinion, this flexibility must be balanced with the need for legal stability required for long-term investments in green infrastructure.

Social Participation and Environmental Equity

Kabisch[46] and Almenar[47] emphasize that nature-based solutions are not mere technical interventions but social processes deeply imbricated with community dynamics and power relations. Cardenas[48] shows that the most successful projects actively involve local communities from design to maintenance, recognizing their specific knowledge and needs.

In some situations, nature-based solutions have exacerbated territorial conflicts or reproduced existing inequalities.[49] This occurs especially when interventions are imposed without adequate consultation, displace traditional land uses, or generate processes of green gentrification that exclude vulnerable populations.[6,15]

Wickenberg[50] stresses the importance of explicitly addressing environmental justice dimensions in the

design of nature-based solutions. This includes considering who benefits from interventions, who bears their costs, and how their impacts are spatially distributed.[18,33]

In the authors' opinion, an encouraging finding is the growing recognition of local and traditional knowledge in the design of nature-based solutions. Experiences with indigenous and peasant communities demonstrate how this knowledge can complement the scientific approach by generating solutions better adapted to specific contexts and with greater local ownership.[41,46,51]

Scalability and Financial Sustainability

The literature review reveals that one of the main challenges for nature-based solutions is their transition from pilot projects to urban or regional scale interventions. Many successful small-scale experiences encounter insurmountable obstacles if they attempt to scale up, due to limitations in technical capacity, continued financing, or inter-institutional coordination.[52,53]

Several innovative financing models that seek to overcome these barriers have been identified, including revolving funds, payment for environmental services, green bonds, and real estate valuation mechanisms. However, these instruments often require institutional and market conditions not present in many contexts, particularly in cities in developing countries.[54,55]

Hekrle[56] shows that maintenance costs are an often underestimated bottleneck. While traditional gray infrastructure has predictable operating costs, nature-based solutions require ongoing adaptive management that is often not adequately budgeted.[9,16] These metrics are essential to justifying public and private investments, but are not yet standardized or widely accepted.

DISCUSSION

The findings of this literature review reveal that the effectiveness of ecosystem-based interventions depends critically on their ability to integrate harmoniously into the natural processes of the territory. However, it is observed that their fragmented or decontextualized implementation can generate results contrary to those expected, by showing the need for more systemic approaches in their planning and execution.[57,58] This challenge is particularly relevant in urban contexts, where pressures on limited space and the urgency for immediate results tend to favor isolated interventions over comprehensive strategies.

A key aspect of the analysis is the importance of institutional arrangements to overcome the frequent disconnect between the policy framework and its concrete implementation. The most successful experiences demonstrate that coordination between different levels of government, combined with precise mechanisms for monitoring and citizen participation, can generate conditions conducive to effectively implementing these solutions.[36,40] However, significant gaps persist in local technical capacity and political will to prioritize ecosystem-based interventions over traditional gray engineering alternatives. These institutional challenges are exacerbated by high staff turnover and limited budgets, where long-term interventions are often disadvantaged.[43,59]

The social dimension emerges as a determining factor for the success or failure of the interventions analyzed. On the contrary, if they are implemented top-down without considering local knowledge and existing community dynamics, they tend to generate resistance or end up abandoned.[49,50] This tension between technical-scientific and local knowledge represents an opportunity to develop hybrid approaches that enrich both the practice and the theory of climate adaptation.

Finally, the results highlight the paradox between the growing recognition of the value of these solutions and the persistent difficulties in financing them at an adequate scale. While there are innovative financing experiences that combine public, private, and community resources, these have not yet overcome the preference for conventional solutions in most public investment processes.[52,60] Progress on this front requires the development of more comprehensive metrics that capture the added value of these interventions in multiple dimensions (ecological, social, economic), as well as more flexible financing mechanisms that allow their adaptation to different contexts and scales. Integrating these lessons learned into public policies represents an urgent challenge in the face of accelerating climate impacts.

CONCLUSIONS

This documentary review shows that Nature-Based Solutions represent a promising paradigm for climate adaptation, but their practical implementation requires overcoming reductionist views that approach them as mere technical interventions. The findings highlight the need for comprehensive approaches that articulate ecological knowledge, multilevel governance, community participation, and innovative financial mechanisms, adapted to the particularities of each territory.

The study suggests three priority directions for research and public policy: strengthening long-term monitoring and evaluation systems, developing flexible institutional frameworks that allow for adaptive learning, and promoting financing models that recognize the multidimensional value of these approaches. Only through this systemic vision can nature-based solutions fulfill their potential as transformative strategies in the face of the climate crisis.

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CONFLICT OF INTEREST

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